DOCUMENT RESUME

ED 219 649 CE 033 506

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TITLE Residential Solar Systems.
INSTITUTION Mid-America Vocational Curriculum Consortium, Stillwater, Okla.
PUB DATE 82
NOTE 198p.
AVAILABLE FROM Mid-America Vocational Curriculum Consortium, 1515 West Sixth Avenue, Stillwater, OK 74074.

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS *Air Conditioning; Behavioral Objectives; Competency Based Education; Criterion Referenced Tests; *Heating; Housing; *Learning Activities; Postsecondary Education; *Solar Radiation; Teaching Methods; Technical Occupations; Test Items; Transparencies; *Units of Study; Vocational Education

ABSTRACT

This publication contains student and teacher instructional materials for a course in residential solar systems. The text is designed either as a basic solar course or as a supplement to extend student skills in areas such as architectural drafting, air conditioning and refrigeration, and plumbing. The materials are presented in four units covering the following topics: fundamentals of solar systems; active solar heating systems; load calculations and solar cooling; and passive solar and other solar concepts. Each unit contains a unit objective, specific objectives, suggested activities, and instructional materials, such as an objective sheet, information sheet, transparency masters, assignment sheets, answers to assignment sheets, job sheets, a unit test, and answers to the test. Suggested references are listed, and the units are liberally illustrated. (KC)

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ED219649

RESIDENTIAL SOLAR SYSTEMS

by

Dan Fulkerson

Developed by the

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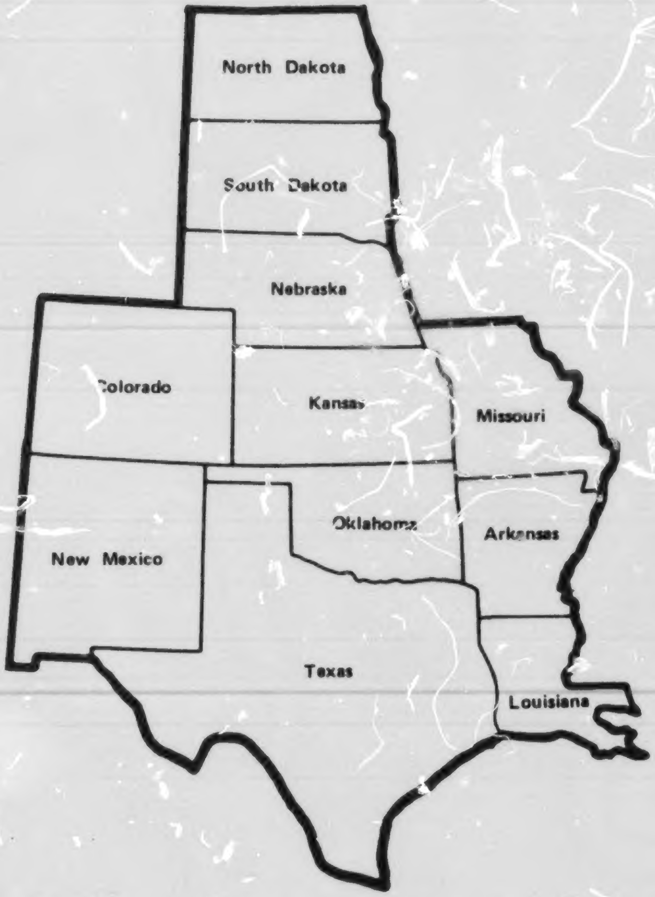
North Dakota
South Dakota
Nebraska
Colorado
Kansas
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Oklahoma
Arkansas
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Texas
Louisiana

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PREFACE

The concept of using solar energy is not a new one; however, the feasibility of using solar applications on residential structures has only now come of age. With increased emphasis being placed in this area, several problems presently exist in our vocational training programs.

Of paramount importance is the need to find quality instructional materials which are up-to-date, economical, and easy to use, as well as flexible enough to fit into many types of programs.

Residential Solar Systems attempts to solve this problem by presenting highly technical solar system processes in an easy to understand format. The materials are presented in four, well illustrated units, and the assignment and job sheets are practical and fun to do. This text is basically designed to supplement other instructional materials and to extend student skills in areas such as architectural drafting, air conditioning and refrigeration, and plumbing, yet it is complete enough to serve almost any basic solar program.

Progress in residential solar applications is crawling along at a time when the urgency created by diminishing fossil-fuel supplies dictates a need to run. We hope that *Residential Solar Systems* will help students and put advances in solar technology to work in residential America.

Ann Benson
Executive Director
Mid-America Vocational
Curriculum Consortium

ACKNOWLEDGEMENTS

Appreciation is extended to those individuals who contributed their time and talents in the development of *Residential Solar Systems*.

The contents of this publication were planned and reviewed by:

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Special appreciation is extended to Jack Hefner and Bill Hill of the Oklahoma State Department staff, representing state level supervision, and to Tom Sutherlin, teacher educator at Cameron University, for their technical assistance with the text.

We extend a special thank you to the Copper Development Association, Inc. for permission to reprint text materials and illustrations from their publication, *Solar Energy Systems*, and to Mr. Conrad D. Gohlinghorst of Stamford, Connecticut for his efforts in making those materials available.

We also express appreciation to the U.S. Department of Energy for their many efforts in solar energy research and application and the many excellent publications those efforts have produced. We have utilized much material from the Department of Energy's *Solar Energy Project* and several of the publications in that series, as well as other materials developed for the Department of Energy under grants and contracts.

Another well deserved thank you goes to the staff members of the Conservation and Renewable Energy Inquiry and Referral Service in Silver Springs, Maryland, for their guidance in selecting material and for their helpful technical advice with several segments of the text.

A special thank you is extended to Leonard Cokeley, southwest district supervisor in the Trade and Industrial Education Division of the Oklahoma State Department of Vocational and Technical Education for his technical assistance in checking the accuracy of information presented in this text.

Appreciation is extended to the Graphics Division of the Oklahoma State Department of Vocational and Technical Education for typing, providing artwork, and printing this publication.

Thanks are also extended to Jane Huston, Mary Kellum, and Dan Fulkerson for their assistance with editing and proofreading.

REFERENCES

(NOTE: This is an alphabetized list of references used in completing this text.)

Logan, Joe D. *Solar Energy: Passive Systems.* St. Louis, MO: Milliken Publishing Co., 1980.

Passive Design Ideas for the Energy Conscious Consumer. Rockville, MD 20850: National Solar Heating and Cooling Information Center, 1979.

Sheet Metal and Air Conditioning Contractors National Association. *Fundamentals of Solar Heating.* Washington, D.C. 20545: U.S. Department of Energy, 1978.

Solar Energy Applications Laboratory, Colorado State University. *Solar Heating and Cooling of Residential Buildings, Design Systems.* Washington, D.C. 20402: U.S. Department of Commerce, 1977.

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The American Planning Association. *Protecting Solar Access for Residential Development: A Guidebook for Planning Officials.* Washington, D.C. 20402: U.S. Department of Housing and Urban Development and U.S. Department of Energy, 1979.

ADDITIONAL REFERENCES

(NOTE: This is an alphabetized list of additional references which would be beneficial as supplemental teaching aids.)

Direct Use of the Sun's Energy. Farrington Daniels; Ballantine Books, Inc., 457 Hahn Rd., Westminster, MD 21157.

Energy for Survival. Wilson Clark (1974); Doubleday & Co., Inc., 277 Park Ave., New York, NY 10017.

Energy Primer. Portola Institute; Whole Earth Truck Store, 558 Santa Cruz Ave., Menlo Park, CA 94025.

Illustrated Solar Energy Guide of Flat-Plate Collectors for Practical Home Application. E.I. & I. Associates, P.O. Box 37, Newbury Park, CA 91320.

Solar Energy and Shelter Design. Bruce Anderson (1973); Total Environmental Action. Church Hill, Harrisville, NH 03450.

Solar Energy for Man. B.J. Brinkworth (1973); John Wiley & Sons, Inc., One Wiley Dr., Somerset, NJ 08873.

Solar Science Projects. D.S. Halacy, Jr.; Scholastic Book Services, 900 Sylvan Ave., Englewood Cliffs, NJ 07632.

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

UNIT OBJECTIVE

After completion of this unit, the student should be able to match types of solar systems with their applications, solve problems concerning rules of thumb for collector tilt and collector orientation, and list components of a typical flat plate solar collector. The student should also be able to construct and use a device to measure solar altitude and solar azimuth and evaluate the use of flat black paint in collecting sensible heat. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to fundamentals of solar systems with their correct definitions.
2. Arrange in order the basic sequence of a solar system operation.
3. Match types of solar systems with their applications.
4. Circle the words which best complete statements concerning elements of solar geometry and their meanings.
5. Solve a problem concerning rules of thumb for collector tilt.
6. Solve a problem concerning rules of thumb for collector orientation.
7. Complete a list of statements concerning components of a typical flat plate collector.
8. Complete a list of statements concerning how the "greenhouse effect" makes a flat plate collector absorb heat
9. Solve a problem concerning the efficiency of flat plate collectors.
10. List two sensible heat storage mediums.
11. Select true statements concerning guidelines for sensible heat storage.
12. Select true statements concerning insolation variables to consider in solar system planning.
13. Determine collector tilt for specific latitudes.
14. Determine collector orientation for specific situations.
15. Demonstrate the ability to:
    a. Construct and use a device to measure solar altitude and solar azimuth.
    b. Evaluate the use of flat black paint in collecting sensible heat.

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Discuss and demonstrate the procedures outlined in the job sheets.

VII. Invite a local or area architect who has designed a solar application to talk to the class about the advantages and problems with solar systems in your specific locale.

VIII. Locate a business or residence in your area where a solar system is in use and invite the person most familiar with the system to talk to the class about its performance.

IX. Check with your local library, nearby university, or community college to find books or other literature about solar, and prepare a list so students will know what reference materials are available in the area.

X. Arrange a visit to a solar supply house or an area business that manufactures collectors or other solar components and have students make brief reports on what they find there.

XI. Arrange to have a representative of your state energy department visit the class and talk about the status of solar and other alternative energy efforts within the state.

XII. Show available films or slide presentations about solar systems.

XIII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

A. Objective sheet

B. Information sheet

C. Transparency masters

1. TM 1--Liquid Heat Storage Options

2. TM 2--Rock-Bed Heat Storage Unit

D. Assignment sheets

1. Assignment Sheet #1--Determine Collector Tilt for Specific Latitudes

2. Assignment Sheet #2--Determine Collector Orientation for Specific Situations

E. Answers to assignment sheets

F. Job sheets

1. Job Sheet #1--Construct and Use a Device to Measure Solar Altitude and Solar Azimuth

2. Job Sheet #2--Evaluate the Use of Flat Black Paint in Collecting Sensible Heat

G. Test

H. Answers to test

II. References:

A. *Solar Energy Systems.* New York, NY 10174: Copper Development Association, Inc., 1979.

B. Solar Energy Applications Laboratory, Colorado State University. *Solar Heating and Cooling of Residential Buildings, Design Systems.* Washington, D.C. 20402: U.S. Department of Commerce, 1977.

C. *Passive Design Ideas for the Energy Conscious Consumer.* Rockville, MD 20850: National Solar Heating and Cooling Information Center, 1979.

D. *Solar Energy Project, Earth Science Activities.* Washington, D.C. 20545: U.S. Department of Energy, 1979.

III. Additional references:

(NOTE: These materials would be beneficial as supplemental teaching aids and can be obtained by writing the below listed addresses.)

A. *Solar Science Projects.* D.S. Halacy, Jr.; Scholastic Book Services, 900 Sylvan Ave., Englewood Cliffs, NJ 07632.

B. *Energy Primer.* Portola Institute; Whole Earth Truck Store, 558 Santa Cruz Ave., Menlo Park, CA 94025.

C. *Direct Use of the Sun's Energy.* Farrington Daniels; Ballantine Books, Inc., 457 Hahn Rd., Westminster, MD 21157.

D. *Energy for Survival.* Wilson Clark (1974); Doubleday & Co., Inc., 277 Park Ave., New York, NY 10017.

E. *Solar Energy and Shelter Design.* Bruce Anderson (1973); Total Environmental Action, Church Hill, Harrisville, NH 03450.

F. *Solar Energy for Man.* B.J. Brinkworth (1973); John Wiley & Sons, Inc., One Wiley Dr., Somerset, NJ 08873.

G. *Illustrated Solar Energy Guide of Flat-Plate Collectors for Practical Home Application.* E.I. & I. Associates, P.O. Box 37, Newbury Park, CA 91320.

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

INFORMATION SHEET

I. Terms and definitions

A. Absorptivity--The ratio of solar energy absorbed by a surface compared to the total amount of solar energy striking the surface

B. Glazing--Glass panes or plastic sheets used to cover solar collectors

C. Greenhouse effect--The tendency of some transparent materials, such as glass, to both transmit and block radiation, resulting in both direct and indirect heat gain

Example: Sunlight shining into a room through a glass window produces a direct heat gain to the immediate area the sun's rays strike, but the radiation is absorbed and stored and also results in an indirect heat gain to adjacent spaces

D. Heat transfer--The transfer of heat from one substance or region to another

E. Sensible heat--Heat that can be physically felt or "sensed" or absorbed by a liquid or solid mass

F. Thermal mass--The potential heat storage capacity of a given substance or system

G. Insolation--The total solar energy received at any given point on the earth's surface

H. Diffuse radiation--Portions of the sun's radiation diffused or scattered by atmospheric particles, clouds, and pollutants; accounts for about 45% of total insolation on a bright, clear day

I. Direct radiation--The remainder of radiation not reflected, absorbed, or diffused that passes more or less directly to the earth's surface from the sun

J. Btu--British thermal unit; the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit

K. Infrared rays--Long-wave rays in solar radiation that are characterized by their heating effect when they strike a surface on the earth

L. Re-emit--The tendency of a material or substance to discharge infrared rays which it has absorbed; sometimes called re-radiation

II. Basic sequence of a solar system operation

A. Available energy must be collected

B. Collected energy must be stored

C. Stored energy must be distributed

INFORMATION SHEET

III. Types of solar systems and their applications

A. Active system--A solar heating or cooling system that uses external mechanical power to move or store solar heat

B. Passive system--A solar heating or cooling system that does not use external mechanical power to move or store solar heat

C. Hybrid system--A solar heating or cooling system which combines both active and passive systems

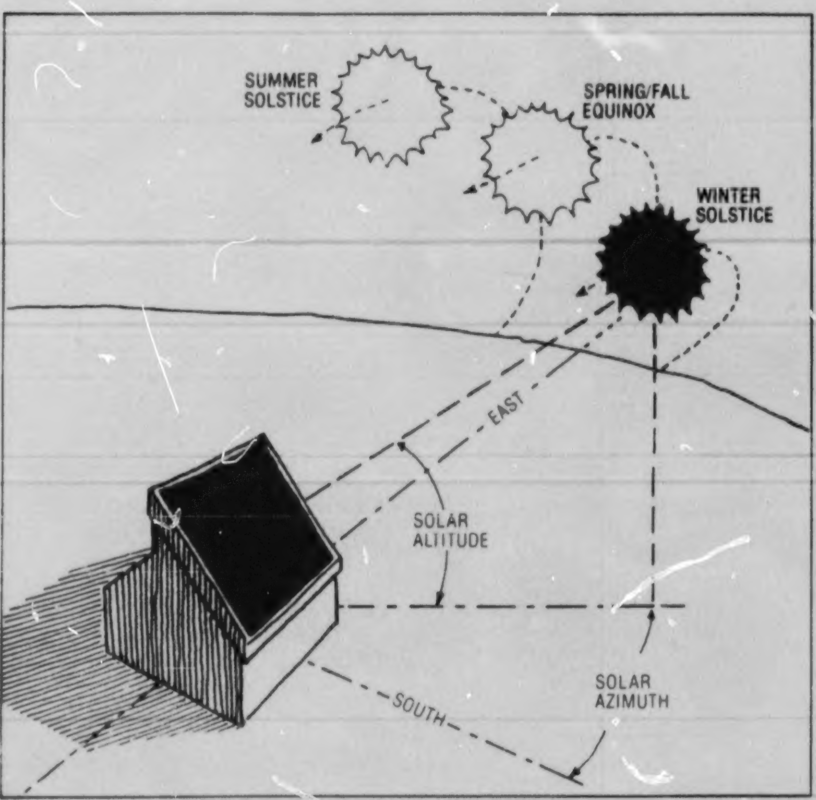
IV. Elements of solar geometry and their meanings (Figure 1)

A. Solar altitude--The angle of the sun's position in the sky with respect to the earth

B. Solar azimuth--The position of the sun with respect to compass directions

(NOTE: Because solar altitude and solar azimuth vary with each day of the year according to latitude, the elements in combination affect both tilt angle and orientation of solar collectors.)

FIGURE 1



Courtesy Copper Development Association Inc.

INFORMATION SHEET

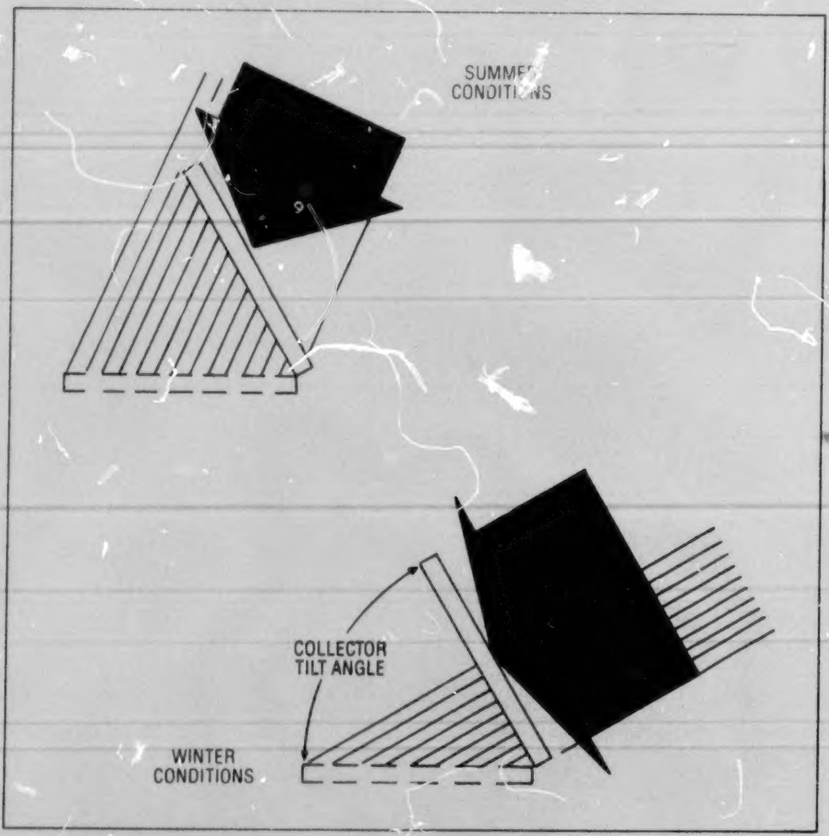
V. Rules of thumb for collector tilt (Figure 2)

A. To collect the most radiation in winter, tilt the collector at an angle equal to the latitude plus 15 degrees

B. To collect the most radiation in summer, tilt the collector at an angle equal to the latitude minus 15 degrees

C. To collect the most radiation averaged over the year, tilt the collector at an angle approximately equal to the latitude

FIGURE 2


SUMMER CONDITIONS
COLLECTOR TILT ANGLE
WINTER CONDITIONS

Courtesy Copper Development Association Inc.

INFORMATION SHEET

VI. Rules of thumb for collector orientation

A. In winter, a south-facing orientation receives more radiation than a southeast or southwest orientation

B. In summer, a south-facing orientation receives slightly less radiation than a south-southeast or a south-southwest orientation

C. In areas that experience morning haze, peak collection may be experienced by a collector which faces 10 to 15 degrees west of south

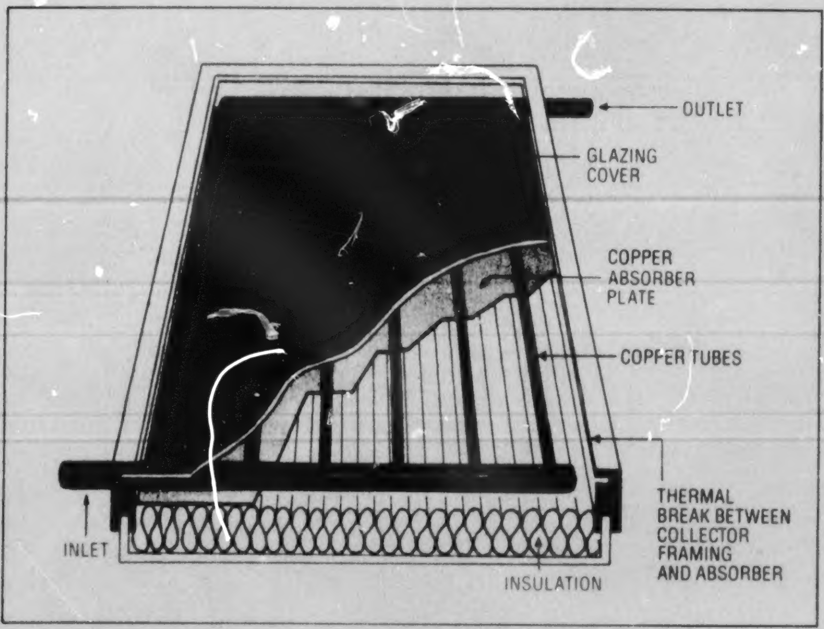
VII. Components of a typical flat plate collector (Figure 3)

A. Flat plate collectors typically use liquid as the heat transfer medium

B. Flat plate collectors typically have blackened copper (sometimes other metals) absorber plates with an integrated or attached array of copper tubes

C. Beneath the absorber plate is an insulating material that retards loss of the absorbed heat through the back of the collector panel

FIGURE 3


OUTLET
GLAZING COVER
COPPER ABSORBER PLATE
COPPER TUBES
THERMAL BREAK BETWEEN COLLECTOR FRAMING AND ABSORBER
INSULATION
INLET

Courtesy Copper Development Association Inc.

INFORMATION SHEET

VIII. How the "greenhouse effect" makes a flat plate collector absorb heat

A. In order to collect as much energy as possible, collectors are often covered with a glazing material of glass or plastic which are highly transparent to incoming solar radiation

B. These covers serve as insulation over the absorber plate and keep convective heat losses down

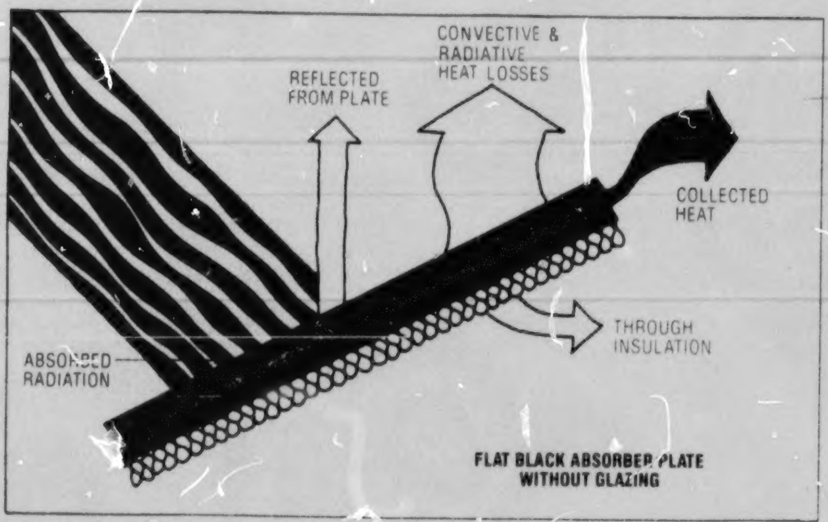
C. Since glass or certain plastics are virtually opaque to the outgoing long-wave infrared radiation, the radiation is trapped inside the collector and this phenomenon in known as the "greenhouse effect"

Example: Greenhouses function because of the effect, but on a larger scale, the earth itself creates a "greenhouse effect" by absorbing solar radiation and turning it into longer wavelength infrared rays; these longer infrared rays cannot easily pass back through the atmosphere into space because certain substances, like carbon dioxide and water in the atmosphere, absorb them; when this energy is prevented from escaping back into space, the "greenhouse effect" occurs.

IX. Efficiency of flat plate collectors

A. In a collector with a flat black absorber plate without glazing, much of the radiation absorbed by the absorber plate is re-emitted or lost from the top surface and some is lost through the back insulation (Figure 4)

FIGURE 4

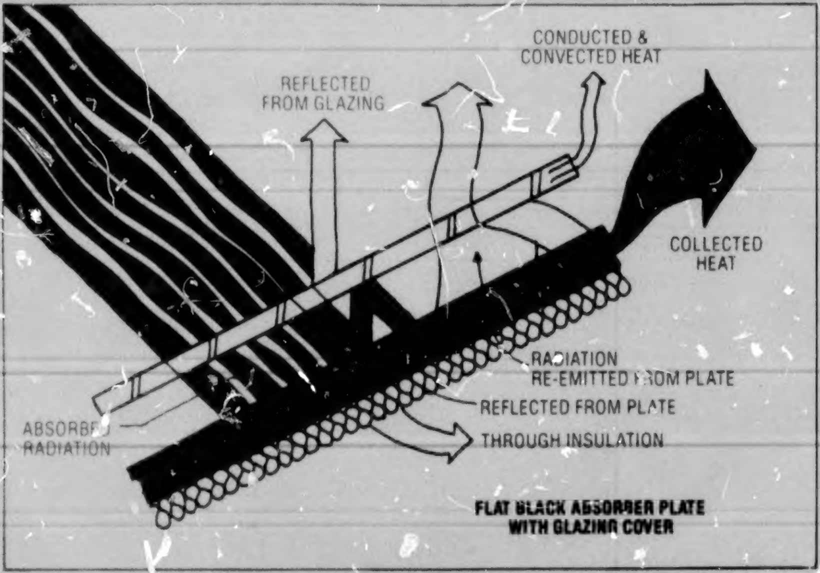

REFLECTED FROM PLATE
CONVECTIVE & RADIATIVE HEAT LOSSES
COLLECTED HEAT
THROUGH INSULATION
ABSORBED RADIATION
FLAT BLACK ABSORBER PLATE WITHOUT GLAZING

Courtesy Copper Development Association Inc.

INFORMATION SHEET

B. In a collector with a flat black absorber plate with glazing cover, the radiation absorbed by the black plate is re-emitted as in the preceding collector, but the glass cover blocks loss of the re-emitted radiation to the outside; there is some loss through conduction and convection, but more heat is retained with a glazing cover (Figure 5)

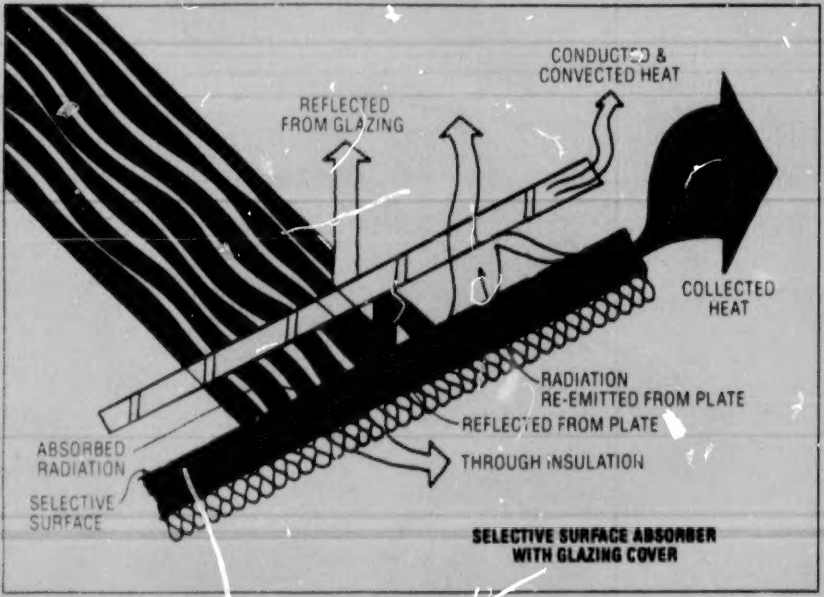
FIGURE 5


CONDUCTED &
CONVECTED HEAT
REFLECTED
FROM GLAZING
COLLECTED
HEAT
RADIATION
RE-EMITTED FROM PLATE
REFLECTED FROM PLATE
THROUGH INSULATION
ABSORBED
RADIATION

FLAT BLACK ABSORBER PLATE WITH GLAZING COVER

C. In a collector with a selective surface absorber with glazing cover, a very thin layer of selected material is applied to the top of the absorber plate; since the layer's thickness is approximately equal to the wavelength of the incoming solar radiation, the selective surface re-radiates much less absorbed energy and is more efficient than other types of collectors (Figure 6)

FIGURE 6


CONDUCTED &
CONVECTED HEAT
REFLECTED
FROM GLAZING
COLLECTED
HEAT
RADIATION
RE-EMITTED FROM PLATE
REFLECTED FROM PLATE
THROUGH INSULATION
ABSORBED
RADIATION
SELECTIVE
SURFACE

SELECTIVE SURFACE ABSORBER WITH GLAZING COVER

Courtesy Copper Development Association Inc.

INFORMATION SHEET

X. Sensible heat storage mediums

A. Water

B. Solid materials such as rock, brick, or adobe

(NOTE: Sensible heat storage is related to the principle of unit heat capacity and the amount of energy required to raise the temperature of a unit volume of a given substance 1°F; although latent heat storage working on the principle of changing the physical properties of a substance would afford smaller solar storage, it is not treated in this unit because the field is still highly experimental; eutectic salts are utilized in latent heat storage, but means of establishing their stability are still being examined.)

XI. Guidelines for sensible heat storage

A. The capacity of sensible heat storage materials is equal to the specific heat of the material times its density (Figure 7)

Example: Water has a specific heat of 1.0 and a density of 62.5 lb./cu. ft.; therefore, one cu. ft. of water will rise in temperature 1°F when 62.5 Btu is applied

FIGURE 7

	Specific Heat BTU/Lb. °F.	Density Lb./Ft.^{3}	Unit Heat Capacity BTU/Ft.^{3}/°F. No Voids	Unit Heat Capacity BTU/Ft.^{3}/°F. 30% Voids
Water	1.0	62.5	62.5	(62.5)
Water (30%)-- Ethylene Glycol (70%) Mixture (230°F.)	.8	64.1	51	36
Scrap Iron	.112	489	55	38
Magnetite	.165	320	53	37
Scrap Aluminum	.215	168	36	25
Concrete	.27	140	38	26
Rock (Basalt)	.20	180	36	25
Brick	.2	140	28	20
Rock Salt (NaCl) (30-70% by weight at 230°F.)	.219	136	30	21

Courtesy Copper Development Association Inc.

INFORMATION SHEET

B. Liquid storage materials are most commonly used with liquid flat plate collectors

C. Solid storage materials are most commonly used with air flat plate collectors

D. A larger volume of solid materials is required to attain the same amount of heat storage as water because the specific heat is much lower for solid materials than for water

E. With solid storage materials, an additional allowance must also be made for the circulation of air around the materials to facilitate heat transfer; this requires a solid-to-void ratio

F. A common solid-to-void ratio for solid sensible heat storage materials is 70 percent solid to 30 percent void

(NOTE: This means that solid heat storage volumes will be two to three times liquid heat storage volumes for the same storage capacity; greater fan motor horsepower is also required to circulate air through a solid storage medium, and larger ductwork is required; these items become important design considerations when selecting a system.)

G. Liquid systems frequently use storage containers made of pre-cast concrete, concrete block, pressure-preserved wood, or rammed earth, and most site-built storage tanks have flexible liners to prevent leaks (Transparency 1)

H. For liquid storage, the most appropriate storage size is 1 1/2 gallons of water per square foot of collector

I. Rock-bed storage should be sized to provide 50 to 100 pounds of rock per square foot of collector, and the rock size should be .75 to 1.5 inches; these sizes insure that the interior of individual rocks can be heated and a good heat flow maintained

J. Rock-bed storage bins can be constructed of wood or pre-cast concrete, but they should be properly sized, insulated, waterproofed against the intrusion of ground water, and sealed with a sealant that will hold up in the high operating temperatures (Transparency 2)

XII. Insolation variables to consider in solar system planning

A. Latitude--Over the course of a year, latitude has the greatest single effect on insolation received at any location

B. Cloud cover--Brings about the greatest day to day variation in insolation at any particular locality, and is the least predictable of any of the variables

C. Atmospheric turbidity--Haze, smoke, fog, or dust that contributes to the reduction in the transparency of the atmosphere and a reduction in insolation

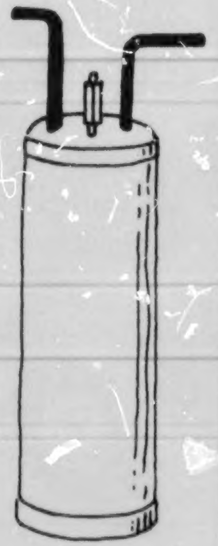
INFORMATION SHEET

D. Altitude--Increased altitude increases the amount of insolation received

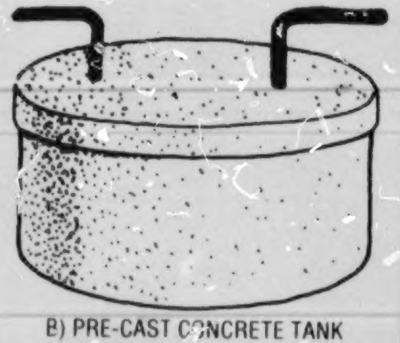
E. Obstructions--Nearby trees and tall buildings can block off the direct rays of sunlight during part of the day, and even if they do not directly block the rays, they may interfere with diffused radiation that would otherwise be received

F. Orientation of the land surface--It is good to remember that most insolation data is for a horizontal surface; planning for sloping sites requires appropriate modifications in data, especially if the slopes are north-facing

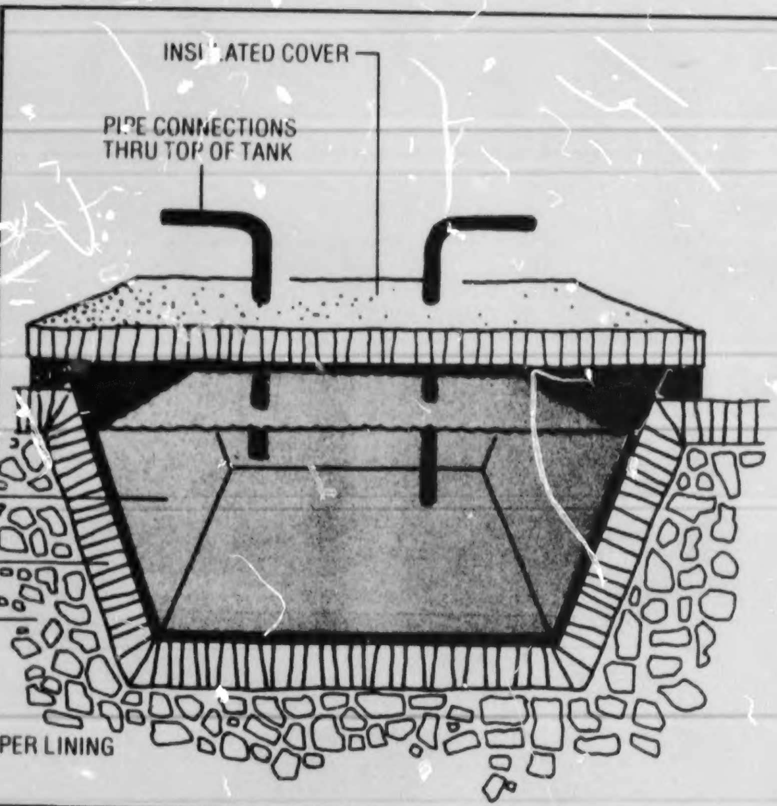
Liquid Heat Storage Options



A) PRESSURE TANK



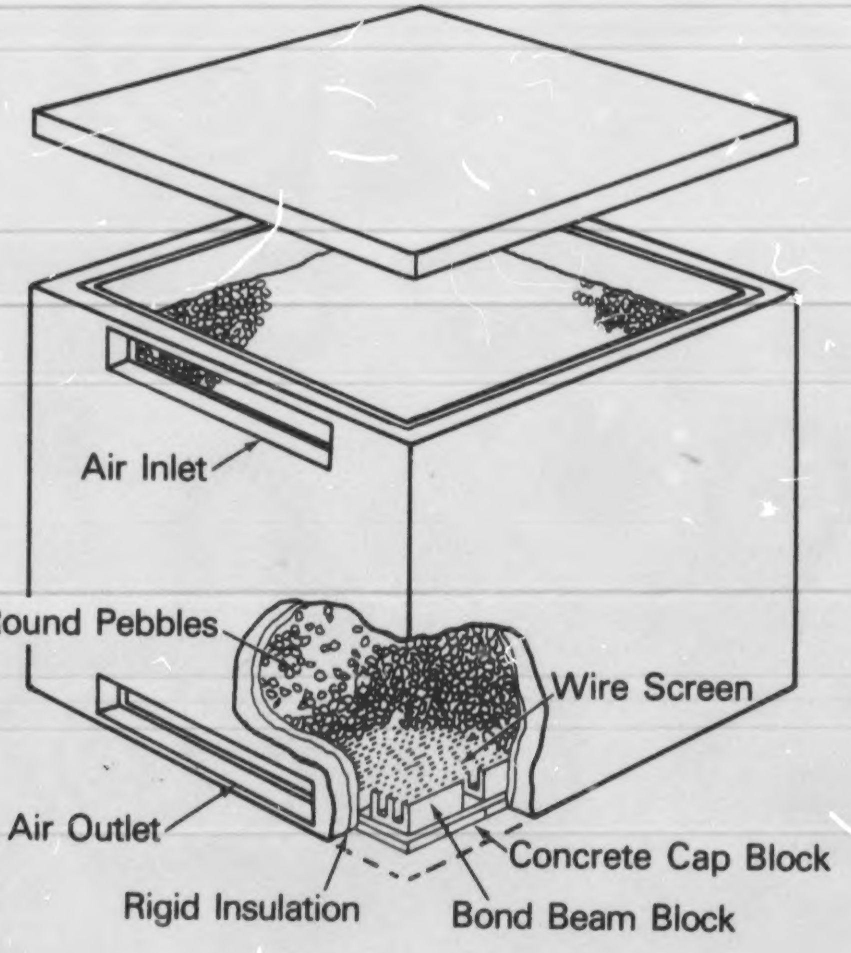
B) PRE-CAST CONCRETE TANK
(MAY BE LINED WITH COPPER)


INSULATED COVER
PIPE CONNECTIONS
THRU TOP OF TANK
FLEXIBLE LINING
INSULATION
RAMMED EARTH

C) RAMMED EARTH WITH FLEXIBLE COPPER LINING

Courtesy Copper Development Association Inc.

Rock-Bed Heat Storage Unit


Air Inlet
¾-1½" Round Pebbles
Wire Screen
Air Outlet
Concrete Cap Block
Rigid Insulation
Bond Beam Block

Courtesy U.S. Department of Energy

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

ASSIGNMENT SHEET #1--DETERMINE COLLECTOR TILT FOR SPECIFIC LATITUDES

A. Determine collector tilt for an application designed to collect the most radiation in winter at a latitude of 40°N

Answer ______________________________

B. Determine collector tilt for an application designed to collect the most radiation in summer at a latitude of 32°N

Answer ______________________________

C. Determine collector tilt for an application designed to collect the most radiation averaged over the year at a latitude of 36°N

Answer ______________________________

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

ASSIGNMENT SHEET #2--DETERMINE COLLECTOR ORIENTATION FOR SPECIFIC SITUATIONS

A. For an application designed to collect the most radiation in winter, should the collector be oriented facing south, southeast, or southwest?

Answer ______________________________

B. For an application designed to collect less radiation in summer, should the collector be oriented facing south, south-southeast, or south-southwest?

Answer ______________________________

C. For an application in an area that experiences morning haze, should the collector be oriented due south or 10 to 15 degrees west of south?

Answer ______________________________

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

A. 55°
B. 17°
C. 36°

Assignment Sheet #2

A. South
B. South
C. 10 to 15 degrees west of south

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

JOB SHEET #1--CONSTRUCT AND USE A DEVICE TO MEASURE SOLAR ALTITUDE AND SOLAR AZIMUTH

I. Tools and materials

A. Small pegboard

B. 3/8-inch wood dowels

C. Magnetic compass

D. Bubble level

E. Clock or watch

F. Paper and pencil

G. Straightedge

H. Protractor

II. Procedure

A. Locate the mid-point of one long edge of the pegboard

B. Place the dowel into the hole six rows in from the mid-point

C. Place a piece of paper on the board by pushing it down over the dowel (Figure 1)

D. Remove the paper from the board

E. Draw two lines on the paper so that both lines pass through the center of the hole with one line parallel to the long side of the paper and one line parallel with the short side of the paper (Figure 1)

(NOTE: These two lines should be perpendicular to each other, at right angles or 90°.)

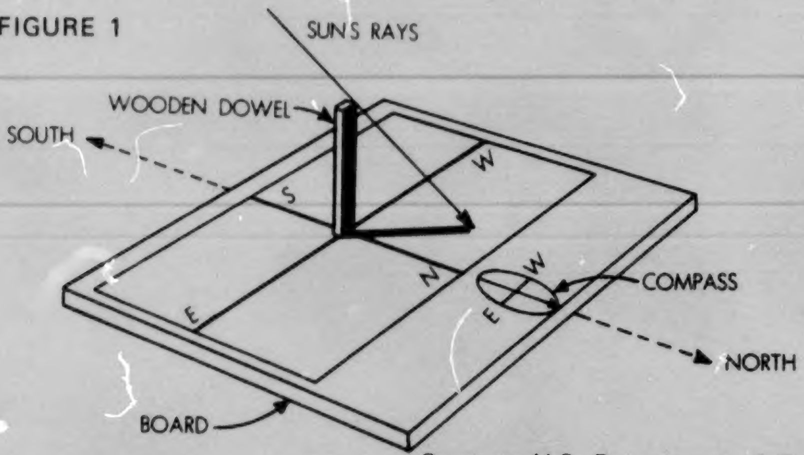
F. Mark the ends N-S, E-W to show compass directions to use in lining the board (Figure 1)

G. Set the board in a horizontal position where it will receive the direct rays of the sun most of the day

JOB SHEET #1

H. Align the board with the compass as shown in Figure 1

FIGURE 1



Courtesy U.S. Department of Energy

I. Use the bubble level to check that the board is level; if needed, level the board

J. Measure and record the height of the dowel above the top surface of the board

K. Begin at zero minutes, and at each 15 minute interval, draw a line on the paper showing the position of the shadow

(NOTE: Be careful to mark the end of the shadow accurately; since positions of the shadows are needed throughout the day, students from other classes may have to work with previously collected data.)

L. Record the time and date for each shadow drawn

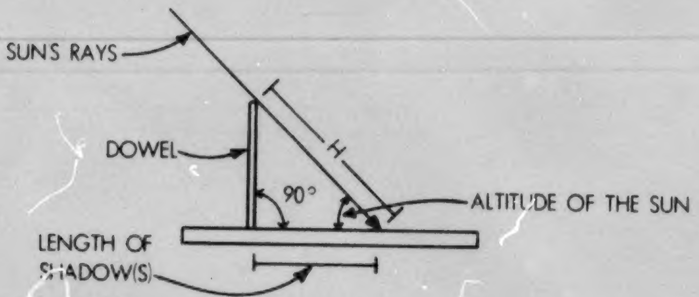
(NOTE: The time should be in increments of 15 minutes.)

JOB SHEET #1

M. Measure the angles of solar altitude and solar azimuth with the following procedure:

1. The first angle is the angle between the shadow (s) on the paper and the slanting angle (H) of the triangle as shown in Figure 2; this angle is called the solar altitude

FIGURE 2


SUNS RAYS
DOWEL
H
90°
ALTITUDE OF THE SUN
LENGTH OF SHADOW(S)

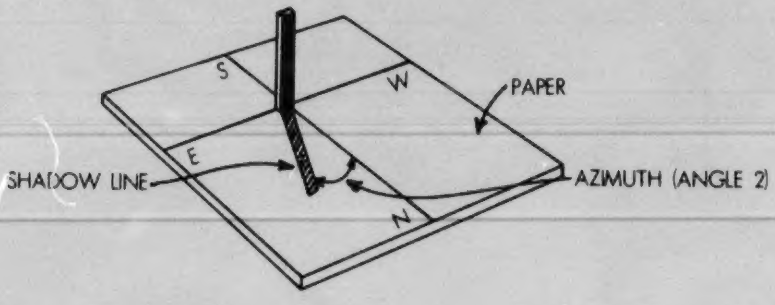
Courtesy U.S. Department of Energy

2. On a separate sheet of paper, draw a right angle triangle so that the vertical side is equal to the dowel height and the horizontal side is equal to the shadow length

3. Draw line (H) and measure angle 1, then record date, time, and altitude of the sun, in degrees, on the diagram

4. The second angle tells how much east or west of the N-S line the sun is; this angle is called the solar azimuth (Figure 3)

FIGURE 3


S
W
PAPER
E
SHADOW LINE
N
AZIMUTH (ANGLE 2)

Courtesy U.S. Department of Energy

JOB SHEET #1

5. Measure angle 2, and record it directly on the apparatus

   (NOTE: Angle 2 in Figure 3 should be recorded as approximately 30°W because the actual position of the sun is west which causes the shadow to be cast to the east; if the actual position of the sun were in the east and the shadow fell the same number of degrees to the west, angle 2 in Figure 3 would be recorded as 30°E; remember that the actual position of the sun is the directional reference for the solar azimuth.)

N. Prepare a data table for the sun's positions, and enter the information in the following chart:

Date:		
Time	Sun's Altitude in degrees	Sun's Azimuth in degrees

JOB SHEET #1

O. Refer to your data to answer the following questions:

1. At what time of day is the sun's shadow shortest? ________________

2. What does this mean? ______________________________

____

3. If you wanted to collect the most energy from the sun, how would you position a solar collector?

____

4. Since most collectors are fixed, which direction should a collector in your area face for best year-round performance?

____

(NOTE: Consider when you are likely to need the most heat.)

5. Could you use your collected data for helping determine the best window placement for a home in your locale?

____

6. Explain your answer to question 5. ________________________

____

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

JOB SHEET #2--EVALUATE THE USE OF FLAT BLACK PAINT IN COLLECTING SENSIBLE HEAT

I. Tools and materials

A. Small can of flat black paint

B. Paintbrush

C. Paint thinner for cleaning brush

D. Clean towel

E. Two 3-pound coffee cans, with plastic lids

F. Thermometer

II. Procedure

A. Paint the outside of one of the coffee cans and plastic lids with flat black paint and allow the paint to dry

B. Fill the two coffee cans almost full with equal amounts of water and put the lids on

C. Place the two cans in direct sunlight far enough apart that one will not shade the other

D. Allow the two cans to sit in direct sunlight for at least four hours

E. Record the outdoor temperature at the end of the testing period ______________________

F. Take the two cans inside, remove the lids, and check the temperature of the water in each can

Unpainted can__________________ Painted can____________________

G. Express the value of the addition of flat black paint to the one can by comparing the water temperature inside the two cans; the addition of flat black paint affects collection and storage of sensible heat (circle one)

Not at all Enough to notice Significantly

H. Clean work area and discuss your findings with your instructor

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

NAME ______________________________

TEST

1. Match the terms on the right with their correct definitions.

_____a. The ratio of solar energy absorbed by a surface compared to the total amount of solar energy striking the surface

_____b. Glass panes or plastic sheets used to cover solar collectors

_____c. The tendency of some transparent materials, such as glass, to both transmit and block radiation, resulting in both direct and indirect heat gain

_____d. The transfer of heat from one substance or region to another

_____e. Heat that can be physically felt or "sensed" or absorbed by a liquid or solid mass

_____f. The potential heat storage capacity of a given substance or system

_____g. The total solar energy received at any given point on the earth's surface

_____h. Portions of the sun's radiation diffused or scattered by atmospheric particles, clouds, and pollutants; accounts for about 45% of total insolation on a bright, clear day

_____i. The remainder of radiation not reflected, absorbed, or diffused that passes more or less directly to the earth's surface from the sun

_____j. British thermal unit; the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit

_____k. Long-wave rays in solar radiation that are characterized by their heating effect when they strike a surface on the earth

_____l. The tendency of a material or substance to discharge infrared rays which it has absorbed; sometimes called re-radiation

1. Insolation
2. Absorptivity
3. Sensible heat
4. Glazing
5. Greenhouse effect
6. Direct radiation
7. Thermal mass
8. Diffuse radiation
9. Heat transfer
10. Re-emit
11. Infrared rays
12. Btu

2. Arrange in order the basic sequence of a solar system operation by placing the correct sequence number in the appropriate blank.

   _____a. Collected energy must be stored

   _____b. Stored energy must be distributed

   _____c. Available energy must be collected

3. Match the types of solar systems on the right with their correct applications.

   _____a. A solar heating or cooling system that uses external mechanical power to move or store solar heat

   _____b. A solar heating or cooling system that does not use external mechanical power to move or store solar heat

   _____c. A solar heating or cooling system which combines both active and passive systems

   1. Hybrid system
   2. Active system
   3. Passive system

4. Circle the words which best complete the following statements concerning elements of solar geometry and their meanings.

   a. Solar altitude--The angle of the sun's position in the sky with respect to (compass directions, the earth)

   b. Solar azimuth--The position of the (sun, earth) with respect to compass directions

5. Solve the following problem concerning rules of thumb for collector tilt: A solar system at 42°N latitude needs a collector that will collect the most radiation during winter months. What would be the best collector tilt?

   ____

6. Solve the following problem concerning rules of thumb for collector orientation: A south-facing collector is not collecting enough winter radiation; an inspection of the collector indicates all components are in good shape; what would best solve the problem?

   ____

7. Complete the following list of statements concerning components of a typical flat plate collector.

   a. Flat plate collectors typically use liquid as the ______________________

   b. Flat plate collectors typically have ______________ absorber plates with an integrated or attached array of copper tubes

   c. Beneath the absorber plate is an insulating material that retards loss of the absorbed heat through the back of the ______________________

8. Complete the following list of statements concerning how the "greenhouse effect" makes a flat plate collector absorb heat.

   a. In order to collect as much energy as possible, collectors are often covered with a glazing material of glass or plastic which are highly transparent to incoming
   ____

   b. These covers serve as insulation over the absorber plate and keep ______________ ______________ down

   c. Since glass or certain plastics are virtually opaque to the outgoing long-wave infrared radiation, the radiation is trapped inside the ______________ and this phenomenon is known as the "greenhouse effect"

9. Solve the following problem concerning the efficiency of flat plate collectors: In planning a solar system installation, it is found that collectors with a selective surface absorber with glazing cost very little more than collectors with flat black absorber plates with glazing; which type of collector should be chosen for the system, and why?

   ____

   ____

   ____

10. List two sensible heat storage mediums.

    a. ______________________________

    b. ______________________________

11. Select true statements concerning guidelines for sensible heat storage by placing an "X" in the appropriate blanks.

    _____a. The capacity of sensible heat storage materials is equal to the specific heat of the material times its volume

    _____b. Liquid storage materials are most commonly used with liquid flat plate collectors

    _____c. Solid storage materials are most commonly used with air flat plate collectors

    _____d. A large volume of solid materials is required to attain the same amount of heat storage as water because the specific heat is much higher for solid materials than for water

    _____e. With solid storage materials, an additional allowance must be made for the circulation of air around the materials to facilitate heat transfer; this requires a solid-to-void ratio

    _____f. A common solid-to-void ratio for solid sensible heat storage materials is 70 percent solid to 30 percent void

    _____g. Solid systems frequently use storage containers made of pre-cast concrete, concrete block, pressure-preserved wood or rammed earth, and most site-built storage tanks have flexible liners to prevent leaks _____h. For liquid storage, the most appropriate storage size is 1/2 gallon of water per square foot of collector

_____i. Rock-bed storage should be sized to provide 50 to 100 pounds of rock per square foot of collector, and the rock size should be .75 to 1.5 inches; these sizes insure that the interior of individual rocks can be heated and a good heat flow maintained

_____j. Rock-bed storage bins can be constructed of wood or pre-cast concrete, but they should be properly sized, insulated, waterproofed against the intrusion of ground water, and sealed with a sealant that will hold up in the high operating temperatures

12. Select true statements concerning insolation variables to consider in solar system planning by placing an "X" in the appropriate blanks.

_____a. Latitude--Over the course of a month, latitude has the greatest single effect on insolation received at any location

_____b. Cloud cover--Brings about the greatest day to day variation in insolation at any particular locality, and is the least predictable of any of the variables

_____c. Atmospheric turbidity--Haze, smoke, fog, or dust that contributes to the reduction in the transparency of the atmosphere and a reduction in insolation

_____d. Altitude--Increased altitude decreases the amount of insolation received

_____e. Obstructions--Nearby trees and tall buildings can block off the direct rays of sunlight during part of the day, and even if they do not directly block the rays, they may interfere with diffused radiation that would otherwise be received

_____f. Orientation of the land surface--It is good to remember that most insolation data is for a vertical surface; planning for sloping sites requires appropriate modifications in data, especially if the slopes are south-facing

13. Determine collector tilt for specific latitudes.

14. Determine collector orientation for specific situations.

15. Demonstrate the ability to:

a. Construct and use a device to measure solar altitude and solar azimuth.

b. Evaluate the use of flat black paint in collecting sensible heat.

(NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

FUNDAMENTALS OF SOLAR SYSTEMS
UNIT I

ANSWERS TO TEST

1. a. 2
   b. 4
   c. 5
   d. 9
   e. 3
   f. 7
   g. 1
   h. 8
   i. 6
   j. 12
   k. 11
   l. 10

2. a. 2
   b. 3
   c. 1

3. a. 2
   b. 3
   c. 1

4. a. The earth
   b. Sun

5. 57°

6. Reorienting the collector to the southeast or southwest

7. a. Heat transfer medium
   b. Blackened copper
   c. Collector panel

8. a. Solar radiation
   b. Convective heat losses
   c. Collector

9. The collectors with selective surface absorbers should be chosen because they are the most efficient and the slight difference in cost will be justified by collector performance

10. a. Water
    b. Solid materials such as rock, brick, or adobe

11. b, c, e, f, i, j

12. b, c, e

13. Evaluated to the satisfaction of the instructor

14. Evaluated to the satisfaction of the instructor

15. Performance skills evaluated to the satisfaction of the instructor

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss basic solar systems used for domestic water heating and space heating, and list the functions of heat pumps in active solar heating systems. The student should also be able to solve problems concerning solar domestic water heating and solar space heating and be able to construct a working model solar water heater. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to active solar heating systems with their correct definitions.
2. Complete a list of statements concerning characteristics of a thermo-syphon domestic hot water system.
3. Circle the words which best complete statements concerning characteristics of a pumped circulation domestic hot water system with heat exchanger.
4. Select true statements concerning characteristics of a pumped circulation domestic hot water system with freeze control.
5. Select true statements concerning characteristics of a pumped circulation domestic hot water system with draindown.
6. List two arrangements for domestic hot water storage tanks.
7. Complete a list of statements concerning characteristics of dual domestic hot water tanks.
8. Circle the words which best complete statements concerning characteristics of a single storage domestic hot water tank.
9. Select true statements concerning characteristics of a combined solar space and domestic hot water system.
10. Complete a list of statements concerning characteristics of a water collection, water storage, air distribution space heating system.
11. Distinguish between a series configuration and a parallel configuration in water collection, water storage, water distribution space heating systems.
12. Complete a list of ways radiant panels are used in water collection, water storage, water distribution space heating systems.

13. Select true statements concerning characteristics of an air collection, solid material storage, air distribution space heating system.

14. Complete a list of characteristics of water collection, water storage, heat pump distribution space heating systems.

15. Distinguish between an air-to-air heat pump and a water-to-air heat pump function in a solar space heating system.

16. Select true statements concerning steps in the operation of an air-to-air heat pump in a solar heating system.

17. Select true statements concerning steps in the operation of a water-to-air heat pump in a solar heating system.

18. Circle the words which best complete statements concerning design considerations for piping systems.

19. Select true statements concerning design considerations for corrosion protection.

20. List four other considerations for corrosion protection.

21. Solve a problem concerning design considerations for collector cover glazing.

22. Complete a list of statements concerning requirements for absorber plate insulation.

23. Solve a problem concerning high temperature protection and its applications.

24. Complete a list of statements concerning rules of thumb for circulating pumps and solar system controis.

25. Solve problems concerning solar domestic water heating systems.

26. Solve problems concerning solar space heating systems.

27. Demonstrate the ability to construct a working model solar water heater.

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment, and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Discuss and demonstrate the procedures outlined in job sheet.

VII. Send for a copy of *Solar Energy Systems* to use as a teaching aid; write to:

Copper Development Association, Inc.
1011 High Ridge Road
Stamford, CT 06905

(NOTE: Much of the information and many of the illustrations in this unit were taken from this publication.)

VIII. Have a local or area architect who has designed a solar system bring the plans to class and discuss planning procedures, system selection, system installation, and system maintenance.

IX. Read Job Sheet #1 carefully and arrange to borrow the required chemical glassware and support equipment from a local high school or college chemistry department.

X. Have a solar dealer bring a solar collector to the classroom, talk about its component structure, and demonstrate its efficiency.

XI. Invite a solar systems dealer to bring solar components such as valves, solenoids, sensors, and dampers to class and talk about their fabrication requirements and their functions within a solar system.

XII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

  A. Objective sheet

  B. Information sheet

C. Transparency masters

   1. TM 1--Pressurized Thermo-Syphon DHW System
   2. TM 2--Pumped DHW System with Heat Exchanger
   3. TM 3--Pressurized Pumped DHW System with Freeze Control
   4. TM 4--Pumped Circulation DHW System with Draindown
   5. TM 5--Dual DHW Storage Tanks
   6. TM 6--Single DHW Storage Tank
   7. TM 7--Combined Solar Space Heating and DHW System
   8. TM 8--Water Collection, Water Storage, Air Distribution Space Heating System
   9. TM 9--Water Collection, Water Storage, Water Distribution Space Heating System
   10. TM 10--Water Collection, Water Storage, Solar Radiant Heating
   11. TM 11--Air Collection, Solid Material Storage, Air Distribution Space Heating System
   12. TM 12--Water Collection, Water Storage, Air-to Air Heat Pump Distribution Space Heating System
   13. TM 13--Water Collection, Water Storage, Water-to-Air Heat Pump Distribution Space Heating System

D. Assignment sheets

   1. Assignment Sheet #1--Solve Problems Concerning Solar Domestic Water Heating Systems
   2. Assignment Sheet #2--Solve Problems Concerning Solar Space Heating Systems

E. Answers to assignment sheets

F. Job Sheet #1--Construct a Working Model Solar Water Heater

G. Test

H. Answers to test

II. References:

A. *Solar Energy Systems.* New York, NY 10174: Copper Development Association, Inc., 1979.

B. Sheet Metal and Air Conditioning Contractors National Association. *Fundamentals of Solar Heating.* Washington, D.C. 20545: U.S. Department of Energy, 1978.

C. Solar Energy Applications Laboratory, Colorado State University. *Solar Heating and Cooling of Residential Buildings, Sizing, Installation, and Operation of Systems.* Washington, D.C. 20545: U.S. Department of Energy, 1977.

D. *Solar Energy Project, Reader.* Washington, D.C. 20545: U.S. Department of Energy, 1979.

E. *Solar Energy Project, Text.* Washington, D.C. 20545: U.S. Department of Energy, 1979.

F. *Solar Energy Project, Earth Science Activities.* Washington, D.C. 20545: U.S. Department of Energy, 1979.

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

INFORMATION SHEET

I. Terms and definitions

A. Aggressive water--Highly mineralized local water supplies that have high levels of dissolved sulfates and chlorides and high PH values

B. DHW--Domestic hot water

C. Thermo-syphon--The circulation of water between a tank and a collector maintained by the natural convection currents that are set up when water is heated

D. Heat exchanger--A device that absorbs heat and then releases it to complete the heat transfer process

E. Toxic--Containing poison

F. Nontoxic--Free of poison

G. Loop--A pipe configuration designed to complete a liquid flow from one given point to another with interconnections among components in a system

H. Solenoid--A valve which mechanically or electronically starts, stops, or diverts flow in a system

I. Sensor--A device which functions as a thermostat to detect changes in temperature; its on-off functions can be set for minimum low or maximum high temperatures

J. One-way check valve--A valve which permits flow in one direction only and prevents flow back to the source

K. Tandem --Working side by side or together

L. Auxiliary storage--A standby or backup storage facility that permits storage of hot water that exceeds the capacity of the prime or system storage facility

M. Auxiliary heat--A standby or backup gas or electric heating system programmed to automatically maintain heating load requirements when the solar system fails to meet the required load demands

N. Heat sink--Body which is capable of accepting, storing, and releasing heat

O. Corrosion--The eating away or wearing away of metals, especially metals in contact with chemicals

P. Dissimilar metals--Any two metals that have different properties

INFORMATION SHEET

Q. Electrolysis--An electro-chemical reaction that causes deterioration when two dissimilar metals come in contact

R. Dielectric--An electric insulator used to control electrolysis at points where dissimilar metals meet

S. Closed system--A solar system into which no air penetrates or from which no air can be expelled

T. Open system--A solar system into which air can penetrate or from which air can be expelled for draindown or to create a syphon effect

U. PH--A symbol for the degree of acidity or alkalinity of a solution; PH is measured on a scale of 0, indicating highest acidity, to 14, indicating highest alkalinity

V. Outgassing--The tendency of certain insulating materials to release elements of their original composition, especially when exposed to high temperatures

W. Damper--A mechanical device, sometimes electronically activated, to stop or moderate flow within a system

II. Characteristics of a thermo-syphon DHW system (Transparency 1)

A. Most basic of solar water heating systems

B. Circulation of water between tank and collector is maintained by natural convection currents set up when water is heated

C. Requires no heat exchanger

(NOTE: Because there is no heat exchanger, the same water that circulates through the collector will later appear at the hot water tap.)

D. When the water in the solar collector becomes hotter than the water in the storage tank, it rises to the tank as the colder tank water drops into the collector supply line

E. When no water is being run at a tap, circulation will continue until tank and collector temperature are equalized

F. Rate of flow cannot be controlled

G. Difficult to provide freeze protection, and system is therefore most appropriate for regions that do not reach freezing temperatures

III. Characteristics of a pumped circulation DHW system with heat exchanger (Transparency 2)

A. Collector water is pumped through a closed pipe loop incorporating a heat exchanger which is immersed in a storage tank

INFORMATION SHEET

B. The closed collector pipe loop must have an expansion tank and a separate pressure relief valve in addition to the valve on the tank

C. Because collected heat must be transferred through a heat exchanger, the collection fluid must be hotter; this makes the system somewhat less efficient than one in which domestic water circulates directly through the collector

D. A check valve in the collector return prevents migration of heat from tank to collector by thermo-syphon action on cold nights

E. Because collector water and domestic water do not intermingle, an antifreeze solution can be added to the collector water for low-temperature protection

(NOTE: Check applicable codes for the use of nontoxic and toxic antifreeze solutions; single-wall heat exchangers may be required with nontoxic antifreeze, and double-wall heat exchangers may be required with toxic antifreeze to provide a double barrier between the toxic antifreeze and potable water.)

IV. Characteristics of a pumped circulation DHW system with freeze control (Transparency 3)

A. System employs a pump but does not use a heat exchanger

B. Collector circuit is not sealed off from stored water, and antifreeze cannot be used

C. Freeze protection is provided by pumping water through the system with a rate of flow high enough to prevent freezing

D. A three-way solenoid valve is the key control element in a pumped circulation system

E. During normal operation, the solenoid valve allows water to circulate freely between tank and collector

F. During normal operation, no cold water is admitted to the system unless a hot water tap is opened in the building, in which case makeup water enters from the supply source

G. In freezing temperatures, the solenoid valve automatically cuts off the storage tank and diverts water from the collector into a dry well or sump, setting up a constant flow of water from the source throught the collector circuit and into the sump

V. Characteristics of a pumped circulation DHW system with draindown (Transparency 4)

A. System incorporates a circulating pump for collector water, but does not employ a heat exchanger

INFORMATION SHEET

- B. System employs a temperature sensor affixed to the bottom of the absorber plate
- C. When the sensor detects a drop to about 40°F, it initiates closing of the motorized valve in the collector supply
- D. When the motorized valve reaches a fully closed position, it trips an end switch which in turn trips the solenoids of both the dump valve and the air intake valve
- E. Water then drains freely from the collector circuit and out of the system

  (NOTE: This drain off is usually no more than two or three gallons, but it does protect all piping exposed to freezing temperatures.)
- F. Pressurized source water is prevented from flowing to the collector by means of a motorized valve in the supply line and a one-way check valve in the return line
- G. When absorber plate temperature rises to a preset difference above storage, the motorized valve begins to open, the circulating pump restarts, and the dump valve and inlet valve close
- H. As the collector circuit refills, trapped air is relieved through the automatic vent and normal circulation of collector water is resumed

VI. Arrangements for DHW storage tanks

- A. Dual solar and conventional tanks
- B. Single storage tanks
- C. Combined solar space and DHW heating systems

VII. Characteristics of dual DHW tanks (Transparency 5)

- A. A larger tank is connected to the collector loop and stores hot water from the collector
- B. In tandum with the larger tank is a conventional water heater with a fossil-fuel burner or an electric heating element
- C. The outlet pipe of the solar storage tank is connected to the cold or inlet line of the conventional heater
- D. Any demand for hot water causes the source water pressure to force water through the solar storage tank, through the conventional tank, and out to a hot water tap
- E. When the solar-heated water is warm enough, it will move through the conventional tank without affecting the thermostat in the conventional tank and without requiring additional heat

INFORMATION SHEET

F. Should the conventional tank water drop below a preset temperature, it will cause the thermostat in the conventional tank to trip and energize the conventional water heater burner or electrode

G. This configuration allows only the relatively cold water to circulate through the collector, and this permits the collector to function at a higher efficiency

VIII. Characteristics of a single storage DHW tank (Transparency 6)

A. Can provide both solar and auxiliary storage in the same tank

B. When this system is used, a large tank should be selected

C. The thermostat of the auxiliary fuel input should be set to maintain a tank temperature of about 110-120°F

D. Because the lowest temperature of water that can be circulated back through the collector is 110°F, collector efficiency is lowered

IX. Characteristics of a combined solar space and DHW system (Transparency 7)

A. Water is heated and stored in a solar storage tank

B. Makeup water for hot water supply passes through a heat exchanger in the solar storage tank

C. If the solar storage tank temperature is high enough, cold domestic makeup water passing through will pick up sufficient heat to avoid drawing energy from the domestic water heater

D. When the temperature of the domestic water tank drops below the storage tank temperature, the domestic water is pumped through the heat exchanger, transferring whatever heat is available

E. When required, an auxiliary heat supply may be programmed to supplement DHW requirements

(NOTE: There are many variations of combination space and water heating systems; sometimes the heat exchanger is placed in the DHW storage tank, and it is also possible to combine a space heating system with a two-tank DHW system.)

X. Characteristics of a water collection, water storage, air distribution space heating system (Transparency 8)

A. These systems have found wide acceptance because they are simple to operate and control

B. The circulating pump in the collector loop operates whenever collector temperature is higher than the temperature of the storage tank water by a preset amount

INFORMATION SHEET

C. When the pump stops, water in the collectors and pipe lines drains into the storage tank

D. To permit the automatic draining process, the return pipe must be coupled to the tank in such a fashion that the end of the pipe is kept above the level of the stored water or the pipe must be vented by some other means

E. When the building thermostat calls for heat, a pump circulates stored water through the heat exchanger coil in the return air duct upstream of the furnace

F. As water is being circulated through the heat exchanger, the furnace fan begins to draw air through the heat exchanger coil and forces the warmed air into the building

G. As long as the coil continues to maintain supply air temperature high enough, the furnace heating element remains off, but when solar supplied heat falls short of preset temperature settings, the furnace comes on to furnish supplementary heat

(NOTE: The placement of thermostats or two-stage thermostats provides several variations in the system described above, and some of these will be discussed in a following objective.)

XI. Differences between a series configuration and a parallel configuration in water collection, water storage, water distribution space heating systems

A. These systems are highly suited for fin tube and radiant panel installations

B. One configuration for this system is that heat can be supplied by either the solar system or the auxiliary boiler working in *series*

C. Another configuration for this system is that heat can be supplied by both the solar system and the auxiliary boiler working in *parallel*

D. In a series configuration, when the solar storage tank is hot enough to supply the heating load, water is pumped from the storage tank through the finned tubes and bypasses the boiler (Transparency 9)

E. In a series configuration, if the storage tank is not hot enough to supply the heating load completely, water is pumped through the boiler and then into the finned tubes, bypassing the storage tank

(NOTE: It is not advisable to pump water from the storage tank, through the boiler, and then through the finned tubes; this would actually use more auxiliary energy and defeat the purposes of the solar component.)

F. In a parallel configuration, if the heating requirement can be supplied by the water from the solar tank, the auxiliary boiler does not operate (Transparency 9)

INFORMATION SHEET

G. In a parallel configuration, when more heat is required than the solar system can supply alone, the boiler kicks in to supplement the solar heat

H. The parallel configuration permits lower temperature water in the solar system to be used to supply a portion of the heating load and actually contributes to higher collector efficiency and more usable solar energy

XII. Ways radiant panels are used in water collection, water storage, water distribution space heating systems (Transparency 10)

A. Radiant panel heating systems employ copper tubes embedded in concrete floor slabs and in wall and ceiling construction

B. Floor installations are the most common with copper coils embedded in concrete with one inch or more of concrete above the tubes and never less than an inch of concrete below the tubes

(NOTE: For slab or grade construction, insulation is imperative beneath the slab; it is also important to insure that ground water will not carry away heat.)

C. Ceiling and wall panels are usually embedded in plaster

D. Wall panel installations require heavy insulation to reduce heat loss to the ouside

(NOTE: Centering coils between rooms or floors is not recommended because it usually results in poor heat transfer and lack of room temperature control.)

XIII. Characteristics of an air collection, solid material storage, air distribution space heating system (Transparency 11)

A. When heat is available for collection, but there is no heat demand in the house, the collector circulation fan begins to draw air down through the storage container

B. Motor operated damper number 3 is open whenever the collector fan is operating and closed at all other times

C. The top portion of the storage container contents will heat first, and the heat will extend downward as more energy is collected

(NOTE: Motor operated damper number 4 is normally open.)

D. When no heat is being collected, but is called for in the building, the centrifugal fan in the auxiliary heating system begins operation and signals dampers 1 and 2 to open

(NOTE: These dampers are closed unless the centrifugal fan is working.)

INFORMATION SHEET

E. Return air is drawn upward through the storage container, exits at maximum temperature, and is circulated through the building

F. When the heating load cannot be supplied by the solar system, the auxiliary heating system comes on

G. When there is a simultaneous collection of energy and demand for heat by the building, motor operated damper 4 is closed

(NOTE: Damper 4 is open unless both collection and distribution fans are operating simultaneously.)

H. Air is circulated directly from the collector to the building

(NOTE: Air-rock systems do have limitations that require special design considerations; these will be covered in a later objective.)

XIV. Characteristics of water collection, water storage, heat pump distribution space heating systems

A. The electrically driven heat pump enhances the flexibility and efficiency of solar systems

B. A heat pump has the capability of extracting heat from a cooler source and increasing it to a higher temperature, thereby increasing the thermal gradient

C. A heat pump can extract useful heat from the solar storage system even when the temperature has fallen below room temperature

XV. Differences between an air-to-air heat pump and a water-to-air heat pump function in a solar space heating system

A. In an air-to-air heat pump, when heating is required, the heat pump extracts heat from one air source (usually the outside air), increases its temperature, and warms the room air (Transparency 12)

B. In a water-to-air heat pump, when heating is required, the heat pump extracts heat from the storage water, increases its temperature, and warms the room air (Transparency 13)

XVI. Steps in the operation of an air-to-air heat pump in a solar heating system (Transparency 12)

A. All solar heating is done directly from storage without the aid of the heat pump, but the heat pump fan is used to circulate room air over the heat exchange coil

B. If heat available from solar storage is insufficient, the heat pump begins to operate, supplying additional heat to the air

INFORMATION SHEET

C. Although this does not permit stored solar energy to be used below the space temperature, it greatly reduces operational time of the heat pump and saves much electricity that would otherwise be used to operate the heat pump compressor

(NOTE: There are other configurations in using a heat pump with a solar system; some permit the heat pump to extract heat from water or solid storage at temperatures below the room temperature, but these systems are complex and require many automatic controls.)

XVII. Steps in the operation of a water-to-air heat pump in a solar heating system (Transparency 13)

A. When the solar storage tank temperature is over a preset point (usually 90°F), storage is used directly for space heating with the heat pump fan circulating the room air over the solar water coil

B. When the storage tank temperature falls below the temperature needed for heating, the control valve changes position and circulates the storage water into the heat pump

C. When the water flow to the heat pump has been proven by a flow switch, the heat pump compressor begins to operate, extracting heat from the water and increasing its temperature; it is then used for warming room air

D. This procedure continues until the heating load has been satisfied or storage tank temperature drops to the lower operating limits of the heat pump (usually about 60°F)

E. Sometimes, other water supplies of appropriate temperature can be used when usable heat in the solar storage tank has been exhausted

F. An auxiliary heat supply is usually required with a water-to-air heat pump solar system

XVIII. Design considerations for piping systems

A. Corrosion is the biggest enemy of piping systems and other solar components

B. It is imperative, from a corrosion standpoint, that the fluid passages in the absorber plate be compatible with the materials used for piping, storage tank, pump, and valve bodies

C. All piping should be pitched from the high point of the system to insure complete drainage when necessary

D. In systems with drainage as freeze protection, the piping should be pitched at a minimum of 1/8 inch per 1 foot of run to insure that fluid will drain completely

INFORMATION SHEET

E. Start up of all liquid-carrying systems should include a flushing operation to remove dirt and debris accumulated during fabrication and installation

(NOTE: Follow manufacturer's recommendations carefully when flushing systems which use a heat transfer fluid other than water.)

XIX. Design considerations for corrosion protection

A. Corrosion protection has three major concerns in metal collector systems:

1. Corrosion between dissimilar metals
2. Use of corrosive liquids
3. Presence of air in the system

B. When dissimilar metals are used in the presence of moisture, corrosion can occur; this is true even of copper when used with another metal

Example: If copper tubes are used to connect aluminum collectors, the collectors soon develop pits in the aluminum fluid tubes and leaks develop

C. In a solar system with a circulating fluid, it is not sufficient simply to use dielectric fittings to separate dissimilar metals and control electrolysis

Example: Copper ions can be carried by the fluid and deposited on other metal and cause pitting

D. Although it is difficult to exclude bronze valves and pump impellers from collector systems, as a general rule, it is best not to mix metals

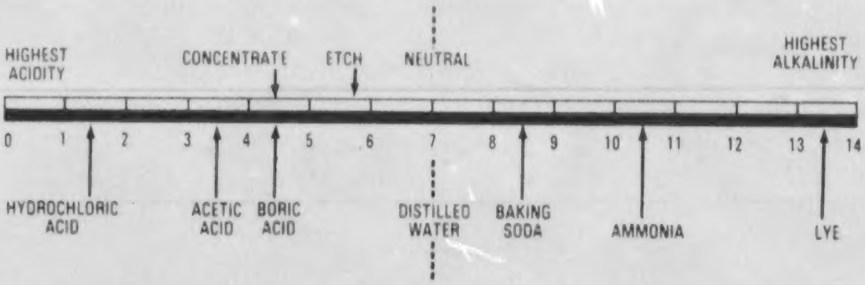
INFORMATION SHEET

XX. Other considerations for corrosion protection

A. Check the local water supply for PH level (Figure 1)

(NOTE: Some areas have "aggressive" waters which are highly mineralized, have a high level of dissolved sulfates and chlorides, have PH values above 7.3, high carbon dioxide content, and the presence of dissolved oxygen gas.)

FIGURE 1



(Courtesy A. B. Dick)

B. A trouble free history of copper plumbing in the locality can usually be taken as evidence that the water is not aggressive to copper, but it may be aggressive to other metals

C. When there is a question concerning the presence of aggressive water, the water should be chemically analyzed, and a treatment engineer should be consulted to prescribe ways to make and keep the water nonaggressive

D. When antifreeze or special heat transfer fluids are added to the water, it increases the potential for corrosion

E. Anti-freezes which are propylene glycol (nontoxic) or ethylene glycol (toxic) based are the two major types of anti-freeze used with water in solar collectors

F. Propylene glycol is claimed to be nontoxic and should be used in DHW systems unless a double walled heat exchanger is employed

G. Anti-freeze solutions usually require the addition of corrosion inhibitors and buffers for PH, and all anti-freeze solutions should be monitored and replenished as required

XXI. Design considerations for collector cover glazing (Figure 2)

A. When using glass cover plates, tempered glass with ground edges should be specified and recommendations for maximum permissable spans should be carefully followed

INFORMATION SHEET

B. When two glass plates are hermetically sealed, they must have the same physical characteristics

Example: A 3/32-inch-thick glass inner plate should not be used with a 3/16-inch-thick tempered cover plate; this would exert substantial internal pressure on the glazing

C. Thin sheets of plastic film can be used for cover plates in certain applications and offer the advantage of light weight, low cost, and increased fracture resistance

D. Plastic selected should have proven long-term resistance to ultraviolet radiation breakdown

E. Additional cover layers reduce heat loss, but there is a point where additional glazing actually diminishes collector efficiency

FIGURE 2

MATERIAL	THICKNESS (INCHES)	SOLAR ENERGY TRANSMISSION (%)	MAXIMUM OPERATING TEMP (°F)
Clear Lime Float Glass	1/8	85.0	400
	3/16	81.0	
	1/4	78.0	
Water White Crystal (Low Iron) Glass	1/8	91.0	400
	3/16	90.5	
	1/4	90.0	
100% Acrylic Colorless Cast Sheet	1/8	89.0	190
	3/16	87.0	
	1/4	85.0	
Polycarbonate	1/8	81.0	270
	3/16	78.0	
	1/4	74.0	
Tedlar Film	0.004	93.5	227
Filon 388	0.060	82.0	220
(Flat) 548	0.030	86.0	
608	0.080	77.0	
Teflon Film	0.002	97.0	400
Mylar Film	0.001	85.0	220
Kalwall Sunlight Regular	0.025	93.0	140
Kalwall Sunlight Premium	0.040	86.0	140
Lexan Film	0.005	94.0	270
	0.007	93.0	

Courtesy Copper Development Association Inc.

INFORMATION SHEET

XXII. Requirements for absorber plate insulation

A. Since absorber plates frequently reach temperatures of more than 200°F, they must be insulated to maximize energy collection from the plate

B. The back of the collector is typically insulated with a 3 to 4-inch thick fiberglass blanket

C. Most foamed urethane insulation currently available undergoes volumetric expansion at temperatures over 250°F and should be used with care, if at all

D. Other insulations have problems with the outgassing of volatile elements which can lead to corrosion and other collector problems

E. Insulation selected should be evaluated according to application needs (Figure 3)

FIGURE 3

	INSULATION		
	FIBERGLASS	URETHANE	EXTRUDED POLYSTYRENE FOAM
Heat Loss	Good	Excellent	Excellent
Moisture Resistance	Fair	Excellent	Excellent
Volatile Outgassing	Excellent	Poor	Fair
Temperature Resistance	Excellent	Fair	Poor
Desirability	Recommended	Not Recommended*	Not Recommended*

*Not recommended for high temperature application
Courtesy Copper Development Association Inc.

XXIII. High temperature protection and its applications

A. Should fluid circulating through an absorber plate stop while the sun is shining, the solar collector can reach temperatures high enough to damage it; this condition is known as stagnation

(NOTE: To avoid collector damage, the collector frame, piping connections, and insulation must be able to withstand high temperatures.)

B. When cooler fluid is pumped into a collector in a condition of stagnation, the resulting thermal shock can cause the collector to buckle and the glazing to break

C. High temperature protection serves to solve problems of stagnation and thermal shock in several ways:

1. One method uses a temperature sensor on the back of the collector plate to actuate a cutout relay in the power supply to the circulating pump; when the collector plate reaches a preselected temperature, power to the pump is cut off preventing circulation of the collector fluid

INFORMATION SHEET

2. Another method employs a timing device that prevents automatic restarting of the pump in the event of a power failure lasting more than a minute or two

3. Still another method employs a temperature sensor to prevent pump operation when a preset temperature differential exists between the collector plate and the circulating fluid

   (NOTE: This is an expensive method and is seldom used in residential applications.)

XXIV. Rules of thumb for circulating pumps and solar system controls

A. Pumps ordinarily selected for residential and small solar applications should be centrifugal types with mechanical shaft seals or totally sealed units

B. Pumps may be close-coupled, in-line, or base-mounted

C. Pump should have a proper combination of flow rate and lift characteristics for the application

(NOTE: Typically, a pump should provide a flow rate of one to three gallons of water per hour, per square foot of collector surface.)

D. In open systems, pumps must have sufficient lifting capacity to raise water from the storage tank to the top of the collector

(NOTE: In closed systems which have high lifting requirements and low flow quantitites, two small pumps connected in series may be a better alternative to overcome friction losses through the piping.)

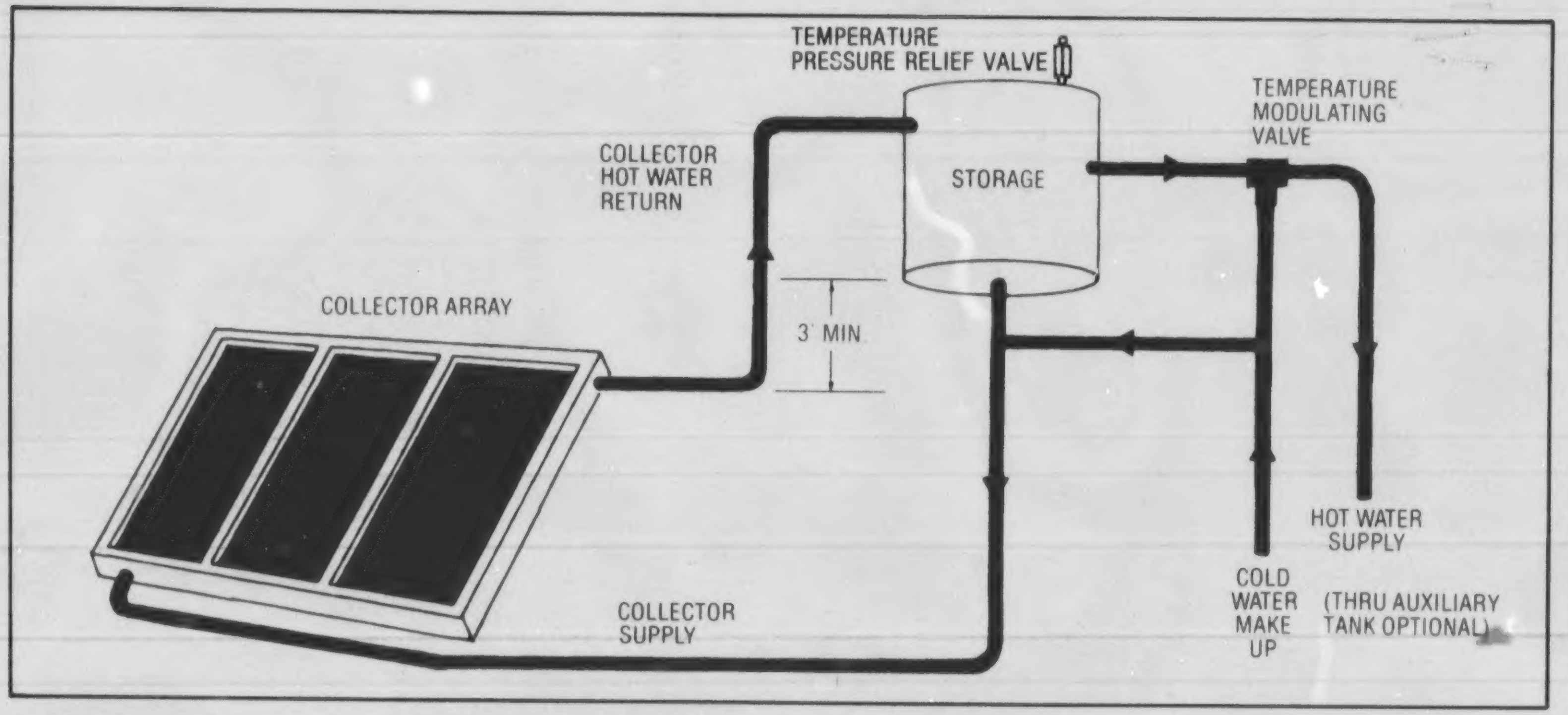
E. In most small solar systems, the pumps will not exceed 1/4 to 1/3 horsepower and may be as small as 1/6 to 1/20 horsepower in closed systems

F. When centrifugal pumps are used, it is essential that they operate with a net positive suction head

(NOTE: This can be accomplished by connecting the pump through the storage tank wall below the water level in the tank; this means there will always be a positive head of water in the tank above the pump.)

G. The circulating pump in the collector loop is normally started or stopped by means of a differential temperature control which actuates the collector pump when the collector temperature is higher than the tank water temperature, and shuts the collector pump off when the collector water temperature approaches the tank temperature

Pressurized Thermo-Syphon DHW System



TEMPERATURE
PRESSURE RELIEF VALVE

TEMPERATURE
MODULATING
VALVE

COLLECTOR
HOT WATER
RETURN

STORAGE

3' MIN

COLLECTOR ARRAY

HOT WATER
SUPPLY

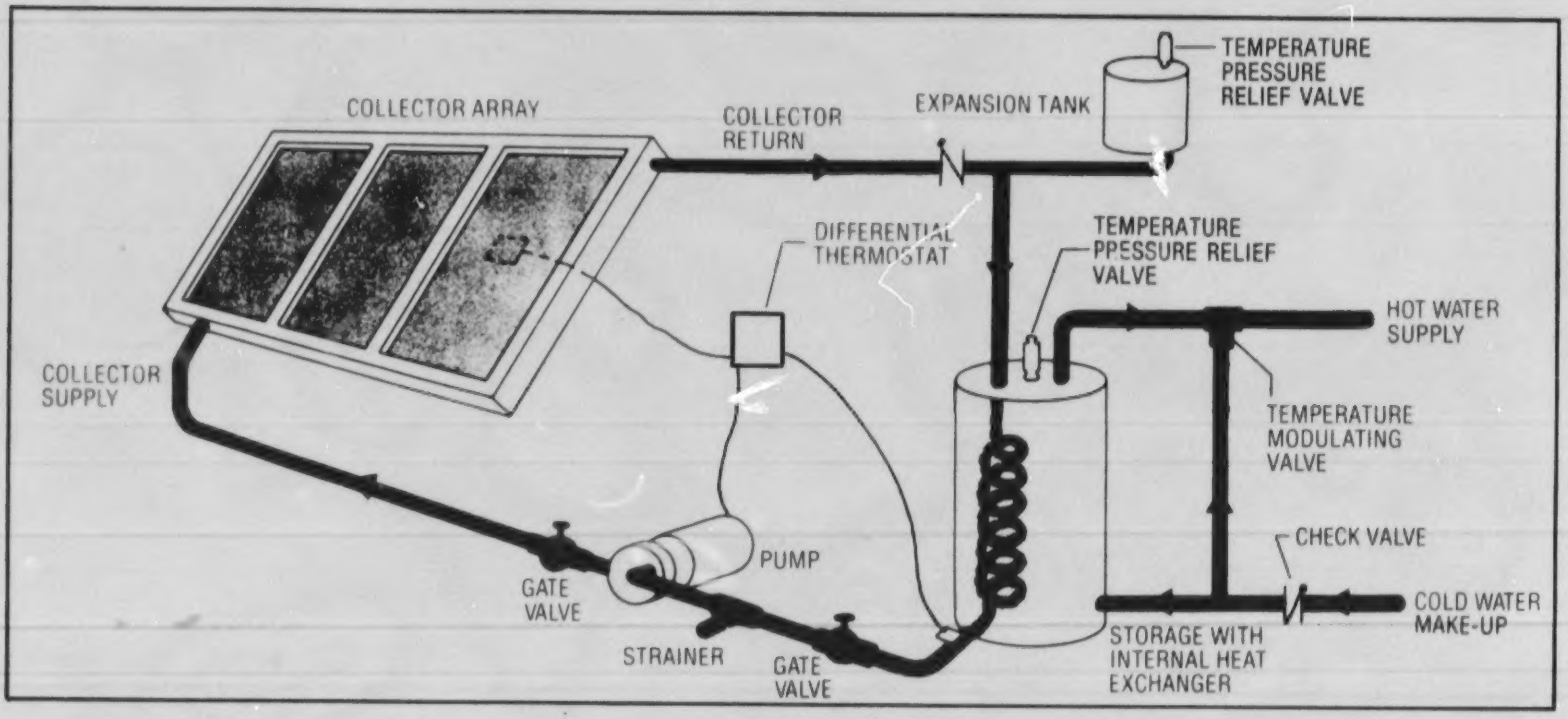
COLD
WATER
MAKE
UP

(THRU AUXILIARY
TANK OPTIONAL)

COLLECTOR
SUPPLY

Courtesy Copper Development Association Inc.

Pumped DHW System with Heat Exchanger


COLLECTOR ARRAY
COLLECTOR RETURN
EXPANSION TANK
TEMPERATURE PRESSURE RELIEF VALVE
DIFFERENTIAL THERMOSTAT
TEMPERATURE PRESSURE RELIEF VALVE
HOT WATER SUPPLY
COLLECTOR SUPPLY
TEMPERATURE MODULATING VALVE
PUMP
CHECK VALVE
GATE VALVE
COLD WATER MAKE-UP
STRAINER
GATE VALVE
STORAGE WITH INTERNAL HEAT EXCHANGER

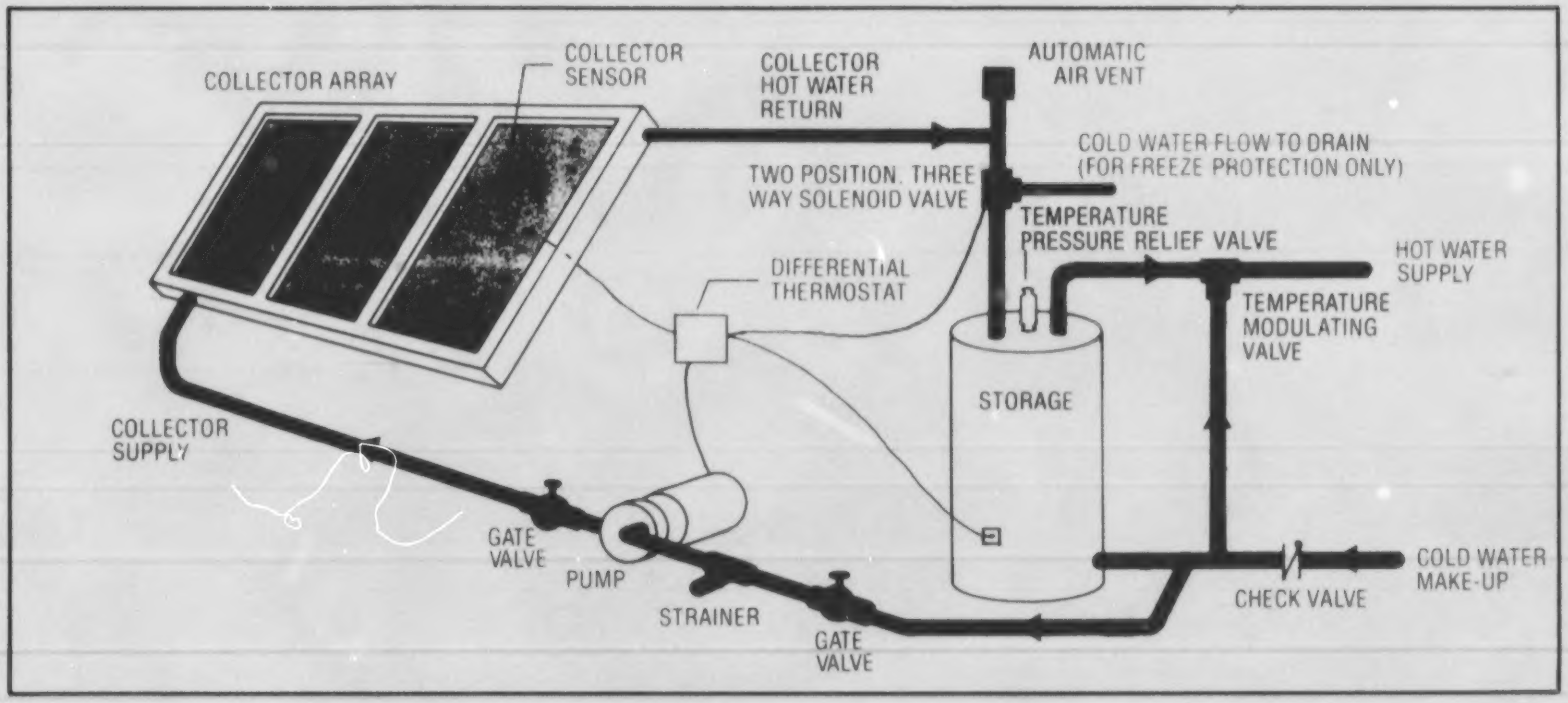
C2

TM 2

Courtesy Copper Development Association Inc.

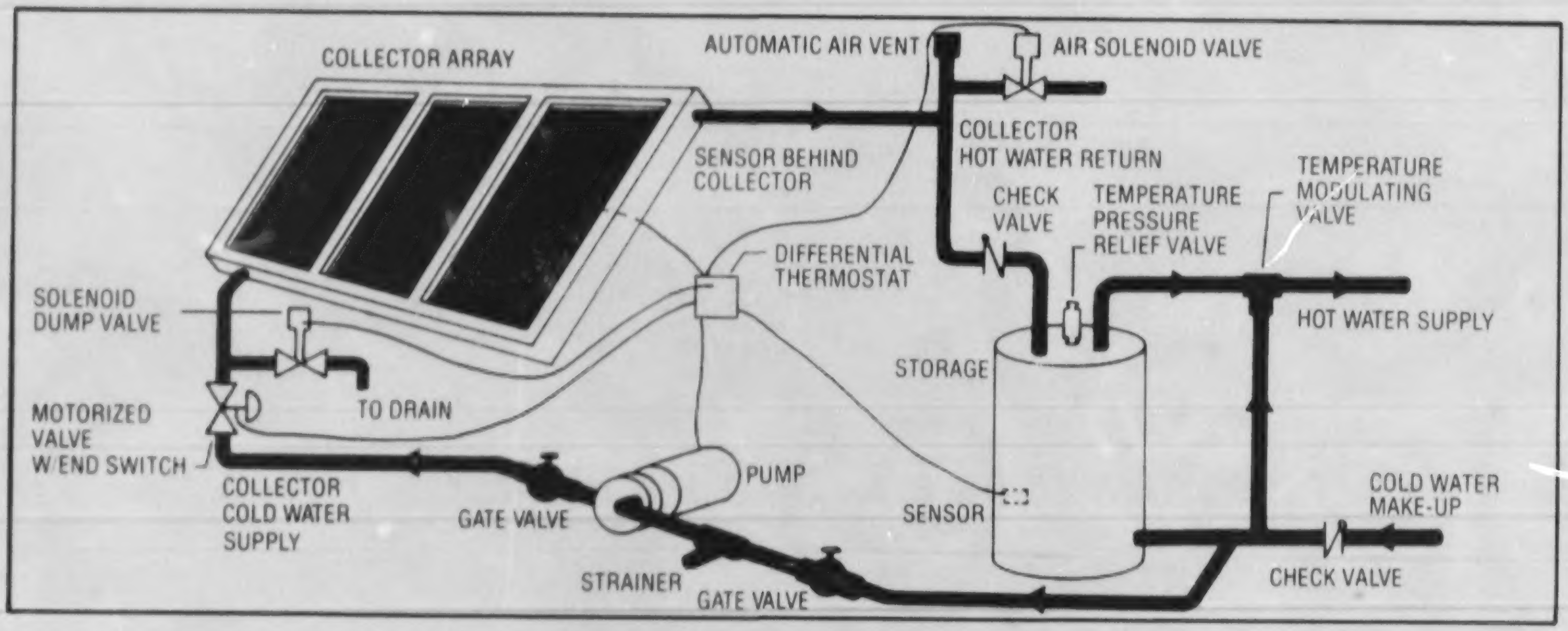
C1

Pressurized Pumped DHW System with Freeze Control


COLLECTOR ARRAY
COLLECTOR SENSOR
COLLECTOR HOT WATER RETURN
AUTOMATIC AIR VENT
COLD WATER FLOW TO DRAIN (FOR FREEZE PROTECTION ONLY)
TWO POSITION, THREE WAY SOLENOID VALVE
TEMPERATURE PRESSURE RELIEF VALVE
HOT WATER SUPPLY
DIFFERENTIAL THERMOSTAT
TEMPERATURE MODULATING VALVE
STORAGE
COLLECTOR SUPPLY
GATE VALVE
PUMP
STRAINER
GATE VALVE
CHECK VALVE
COLD WATER MAKE-UP

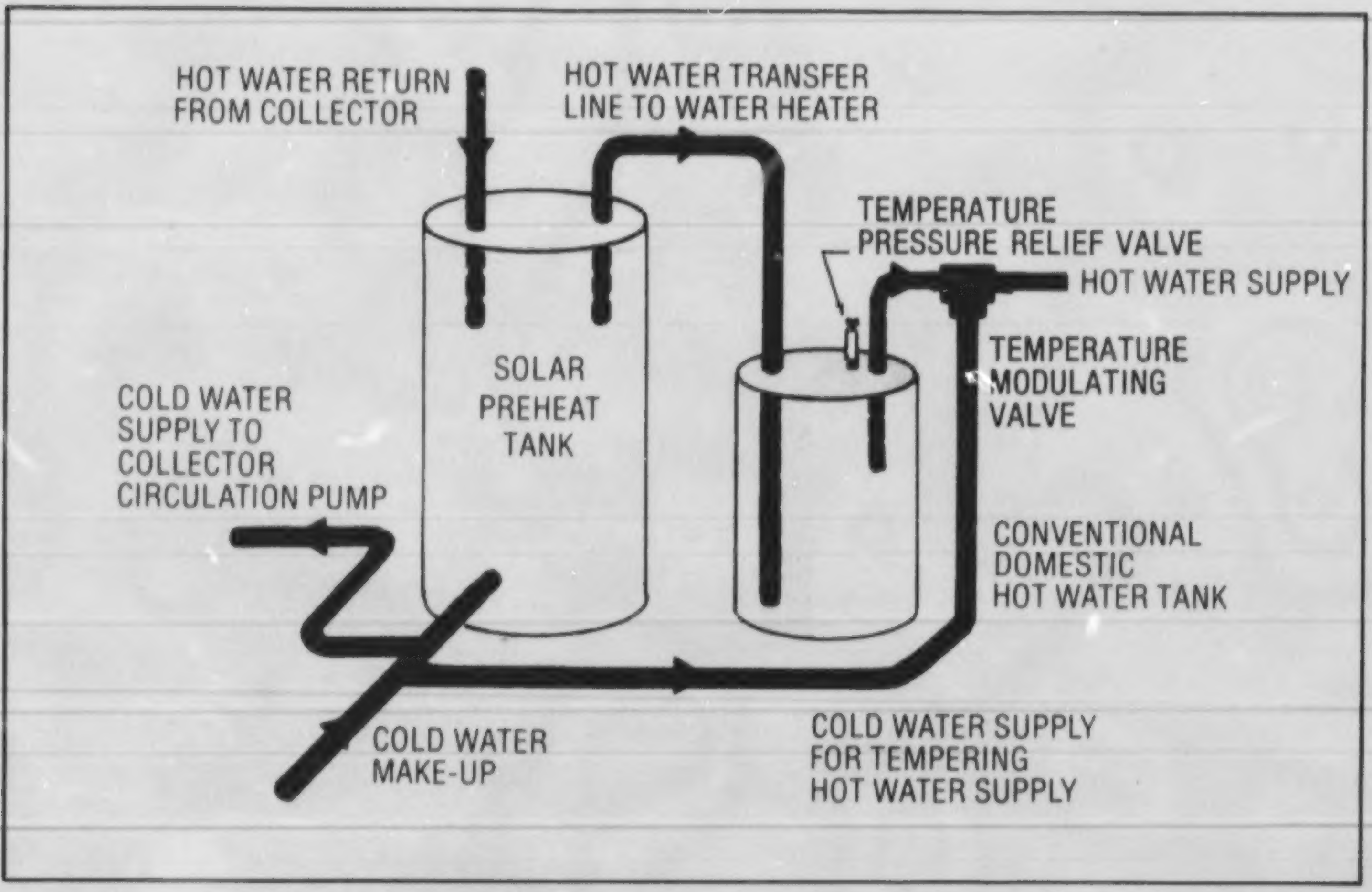
Courtesy Copper Development Association Inc.

Pumped Circulation DHW System with Draindown


COLLECTOR ARRAY
AUTOMATIC AIR VENT
AIR SOLENOID VALVE
COLLECTOR
HOT WATER RETURN
SENSOR BEHIND
COLLECTOR
CHECK
VALVE
TEMPERATURE
PRESSURE
RELIEF VALVE
TEMPERATURE
MODULATING
VALVE
DIFFERENTIAL
THERMOSTAT
SOLENOID
DUMP VALVE
HOT WATER SUPPLY
STORAGE
TO DRAIN
MOTORIZED
VALVE
W/END SWITCH
PUMP
COLLECTOR
COLD WATER
SUPPLY
GATE VALVE
SENSOR
COLD WATER
MAKE-UP
STRAINER
GATE VALVE
CHECK VALVE

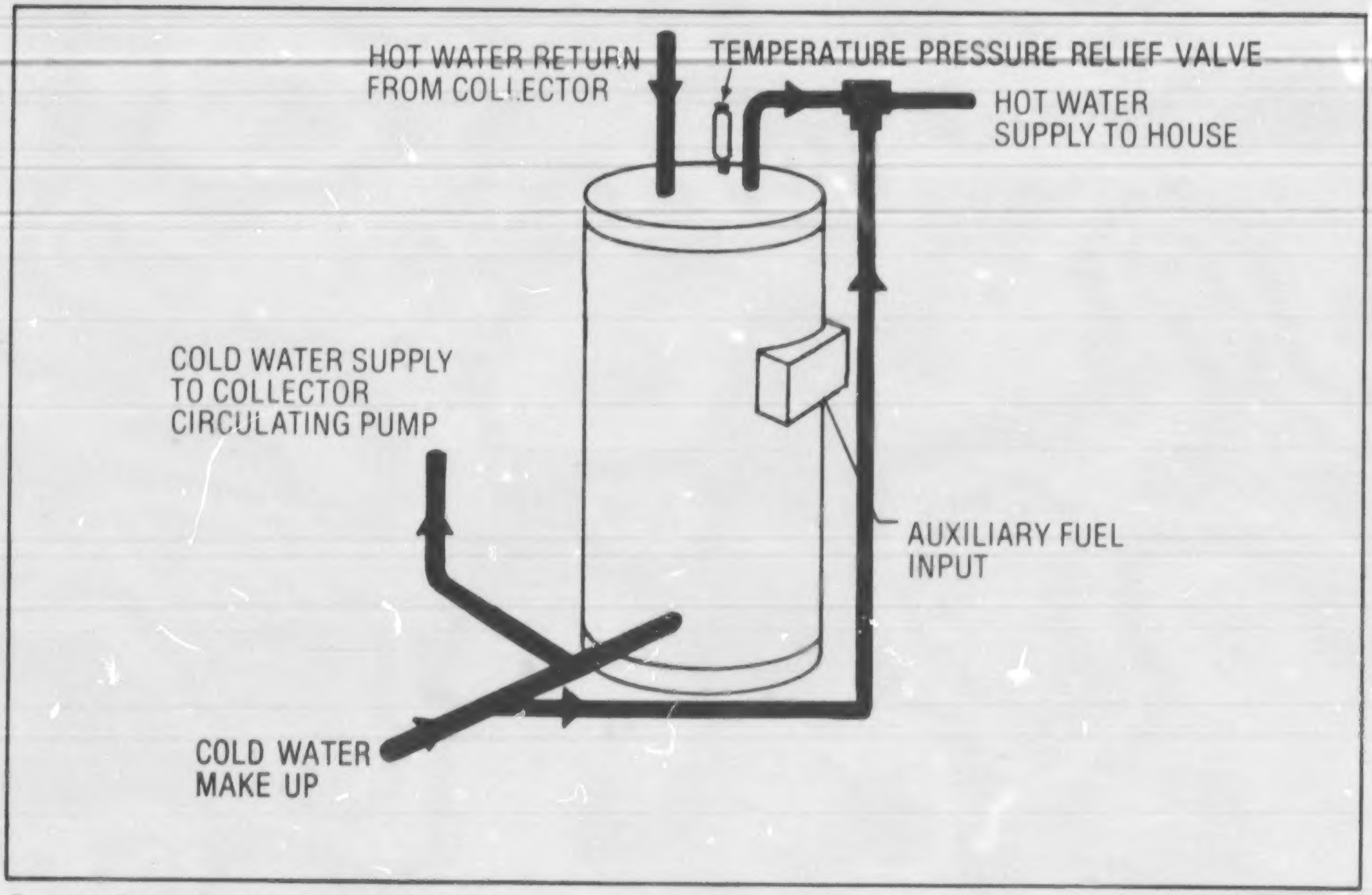
Courtesy Copper Development Association Inc.

Dual DHW Storage Tanks


HOT WATER RETURN FROM COLLECTOR
HOT WATER TRANSFER LINE TO WATER HEATER
TEMPERATURE PRESSURE RELIEF VALVE
HOT WATER SUPPLY
SOLAR PREHEAT TANK
TEMPERATURE MODULATING VALVE
COLD WATER SUPPLY TO COLLECTOR CIRCULATION PUMP
CONVENTIONAL DOMESTIC HOT WATER TANK
COLD WATER MAKE-UP
COLD WATER SUPPLY FOR TEMPERING HOT WATER SUPPLY

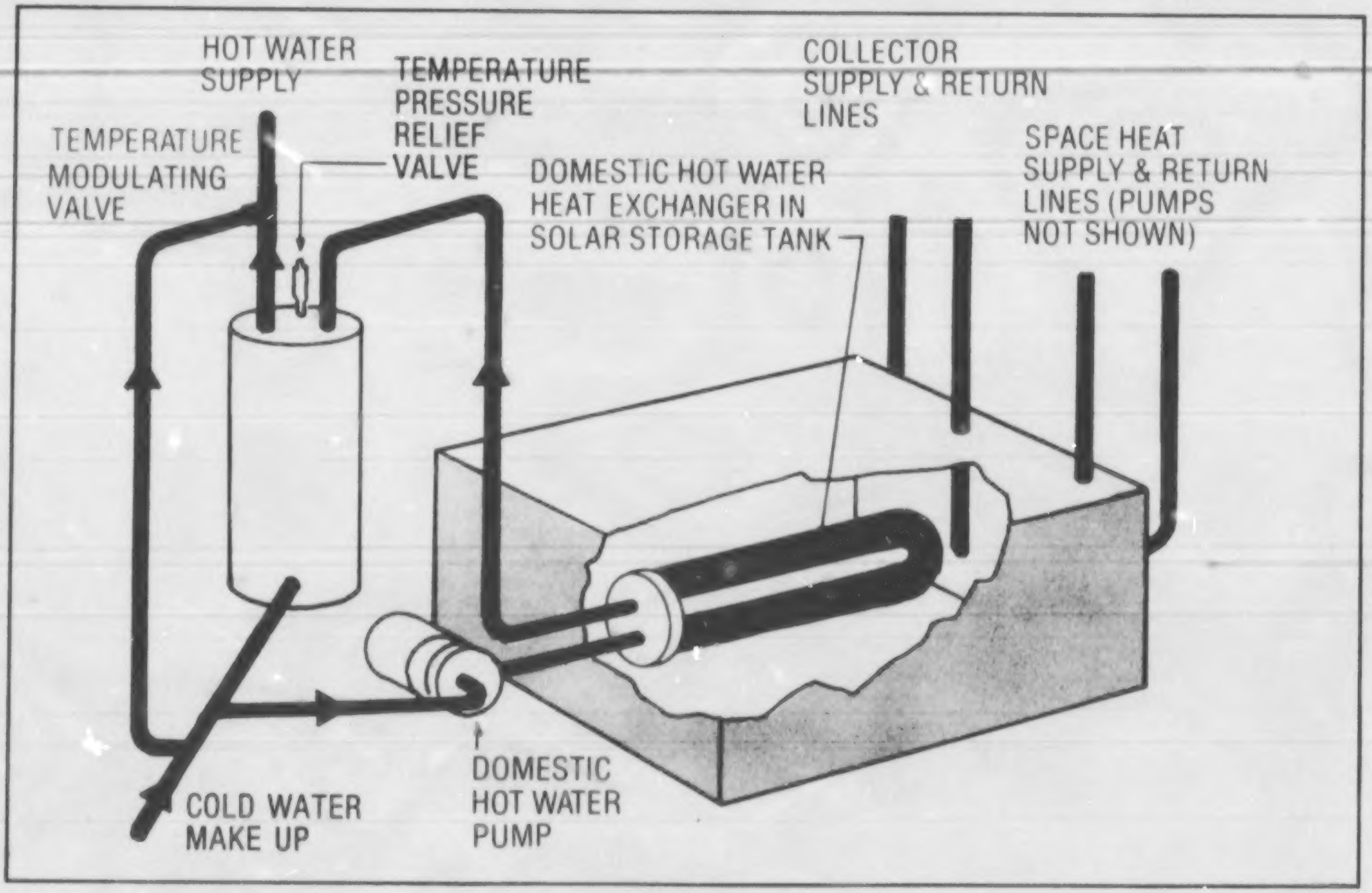
Courtesy Copper Development Association Inc.

Single DHW Storage Tank


HOT WATER RETURN FROM COLLECTOR
TEMPERATURE PRESSURE RELIEF VALVE
HOT WATER SUPPLY TO HOUSE
COLD WATER SUPPLY TO COLLECTOR CIRCULATING PUMP
AUXILIARY FUEL INPUT
COLD WATER MAKE UP

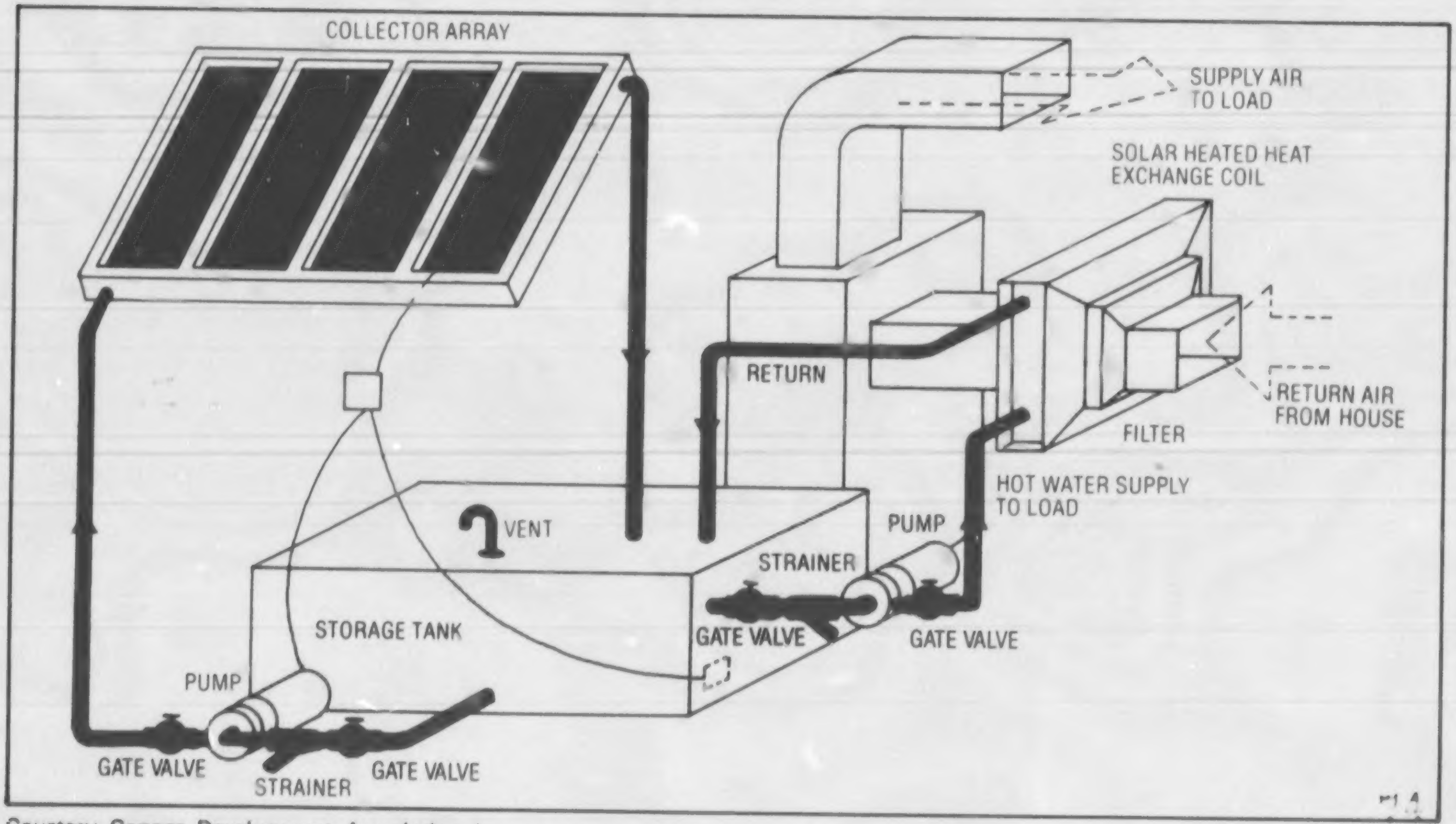
Courtesy Copper Development Association Inc.

Combined Solar Space Heating and DHW System


HOT WATER SUPPLY
TEMPERATURE PRESSURE RELIEF VALVE
TEMPERATURE MODULATING VALVE
COLLECTOR SUPPLY & RETURN LINES
SPACE HEAT SUPPLY & RETURN LINES (PUMPS NOT SHOWN)
DOMESTIC HOT WATER HEAT EXCHANGER IN SOLAR STORAGE TANK
COLD WATER MAKE UP
DOMESTIC HOT WATER PUMP

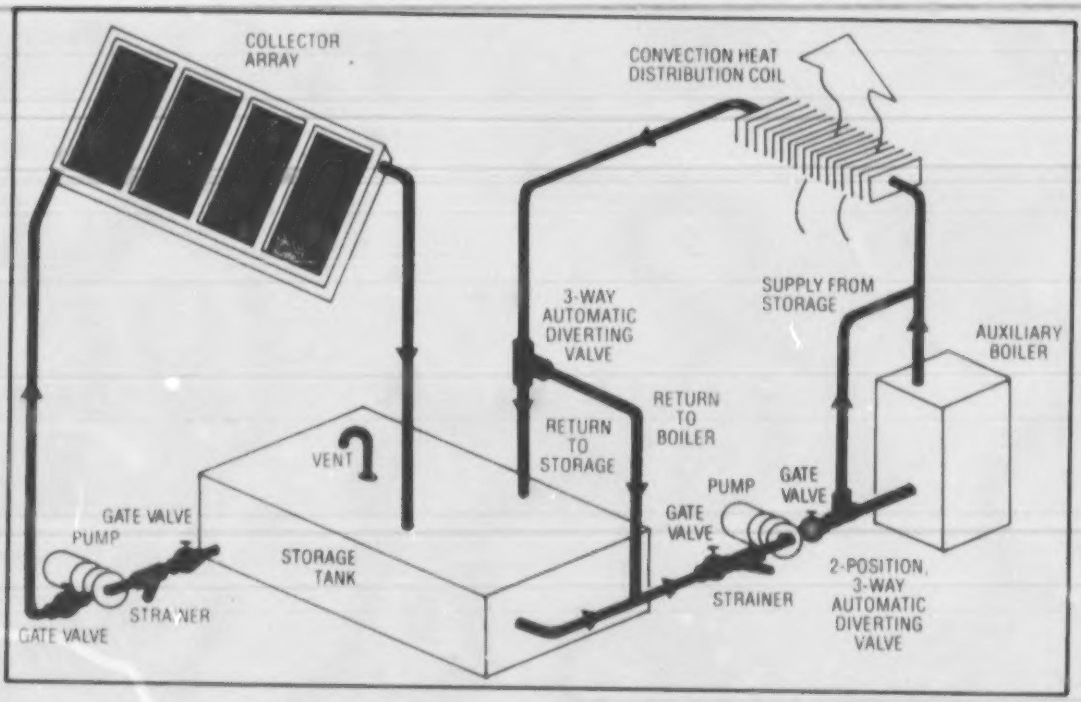
Courtesy Copper Development Association Inc.

Water Collection, Water Storage, Air Distribution Space Heating System

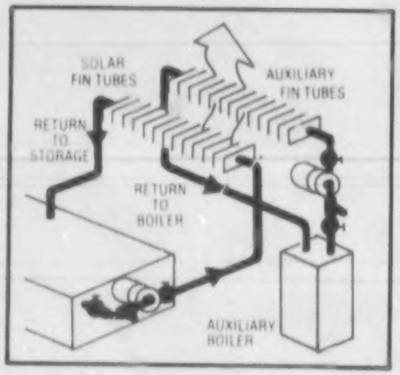

COLLECTOR ARRAY
SUPPLY AIR TO LOAD
SOLAR HEATED HEAT EXCHANGE COIL
RETURN
RETURN AIR FROM HOUSE
FILTER
HOT WATER SUPPLY TO LOAD
PUMP
VENT
STRAINER
STORAGE TANK
GATE VALVE
GATE VALVE
PUMP
GATE VALVE
STRAINER
GATE VALVE

Courtesy Copper Development Association Inc.

Water Collection, Water Storage, Water Distribution Space Heating System


COLLECTOR ARRAY
CONVECTION HEAT DISTRIBUTION COIL
3-WAY AUTOMATIC DIVERTING VALVE
SUPPLY FROM STORAGE
AUXILIARY BOILER
RETURN TO BOILER
RETURN TO STORAGE
VENT
PUMP
GATE VALVE
GATE VALVE
PUMP
GATE VALVE
STORAGE TANK
STRAINER
GATE VALVE
STRAINER
2-POSITION, 3-WAY AUTOMATIC DIVERTING VALVE

Series Configuration


SOLAR FIN TUBES
AUXILIARY FIN TUBES
RETURN TO STORAGE
RETURN TO BOILER
AUXILIARY BOILER

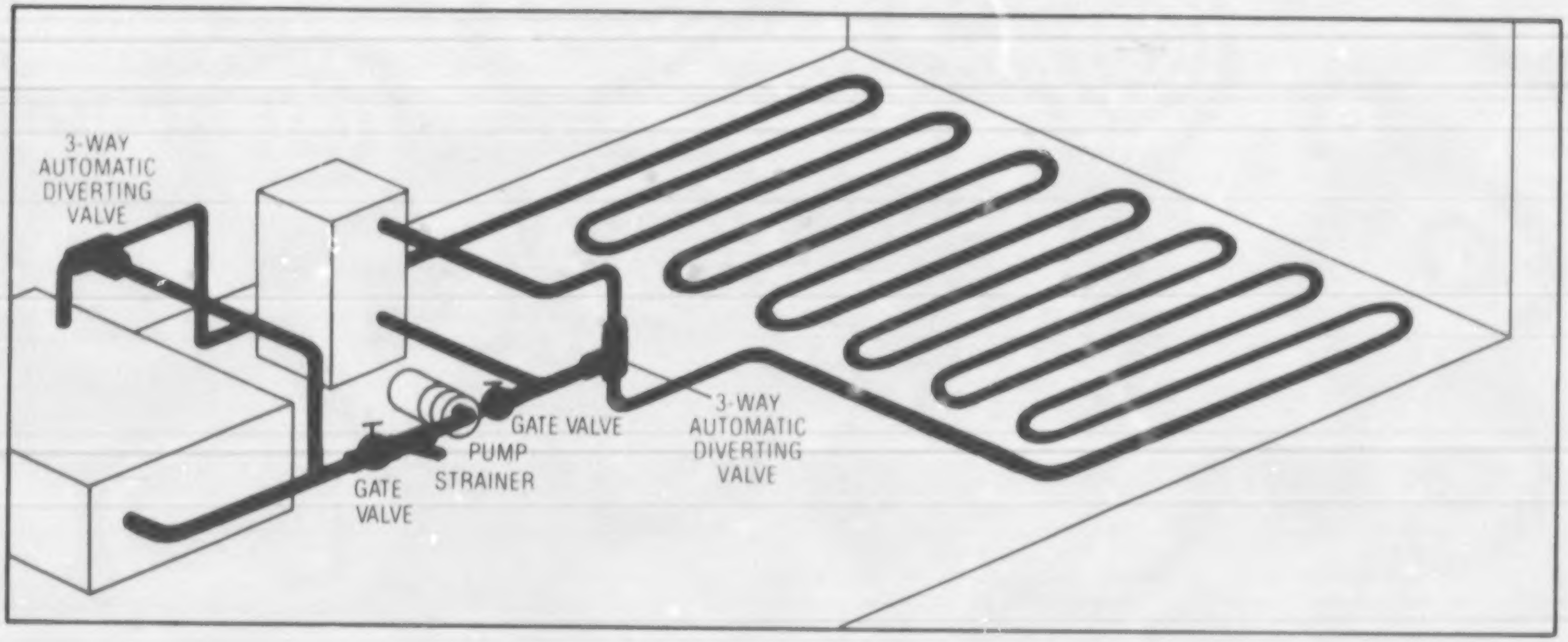
Parallel Configuration

TM 9

Courtesy Copper Development Association Inc.

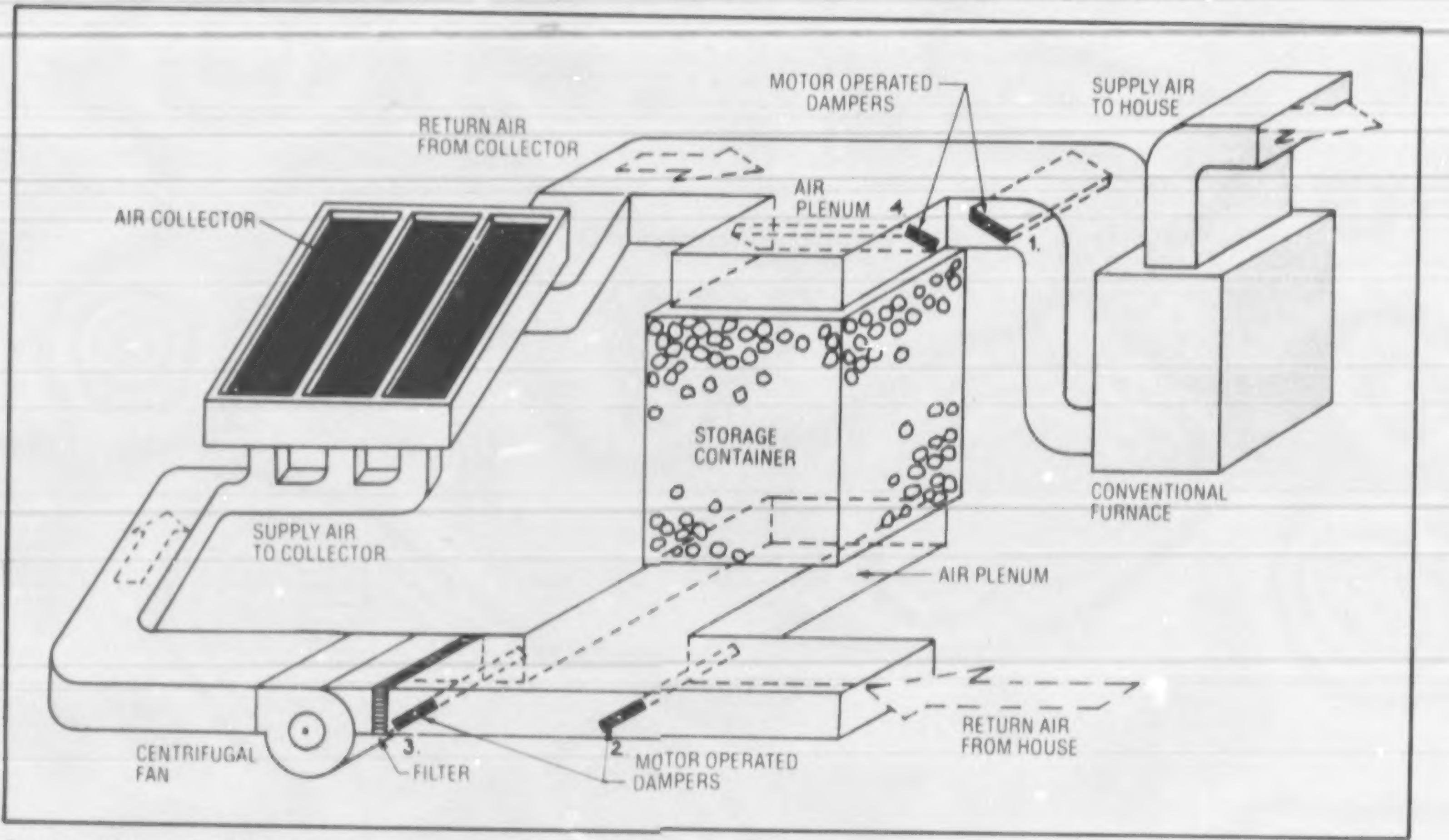
RS-77

Water Collection, Water Storage, Solar Radiant Heating


3-WAY AUTOMATIC DIVERTING VALVE
GATE VALVE
PUMP
STRAINER
GATE VALVE
3-WAY AUTOMATIC DIVERTING VALVE

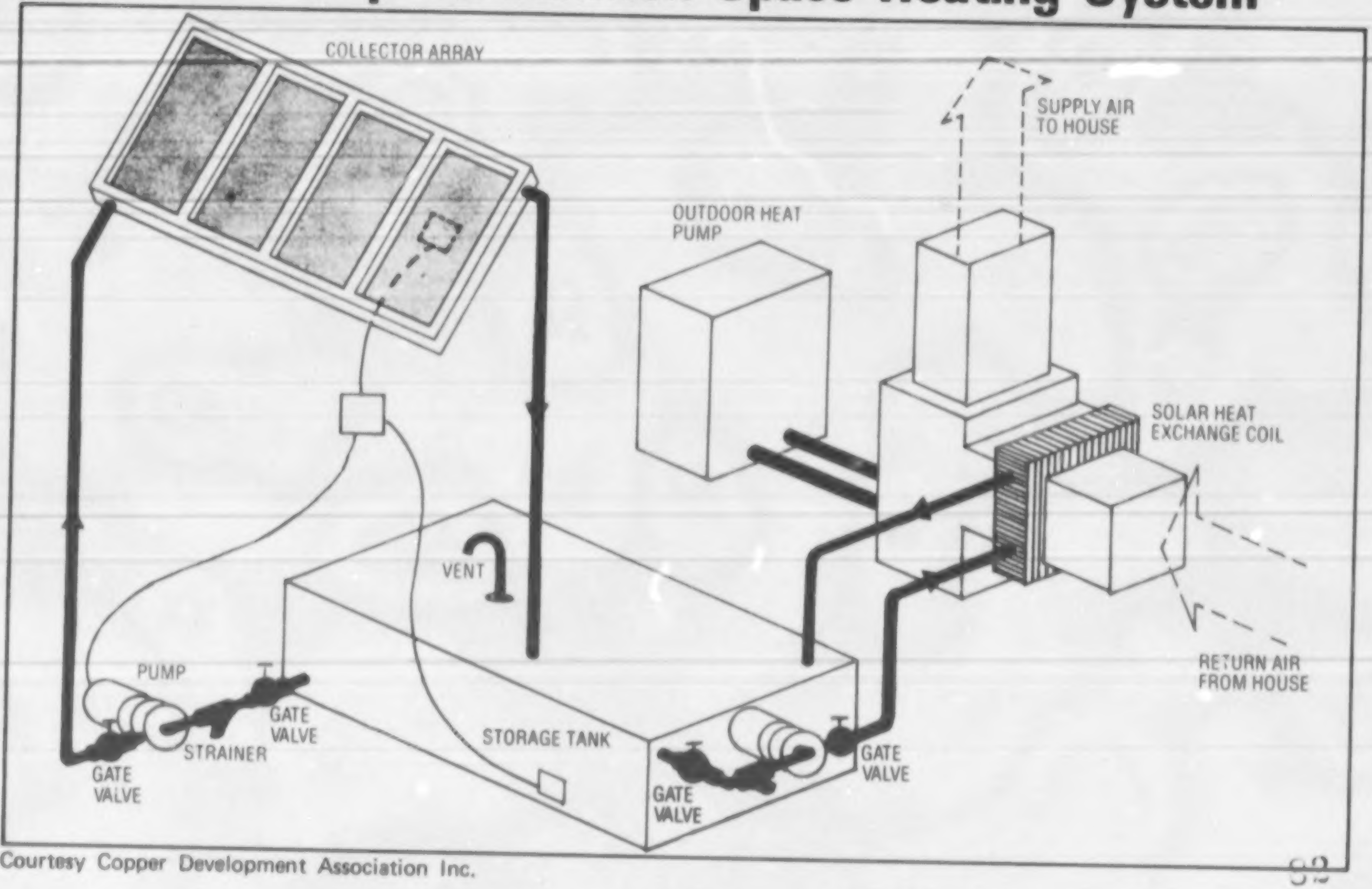
Courtesy Copper Development Association Inc.

Air Collection, Solid Material Storage, Air Distribution Space Heating System


MOTOR OPERATED DAMPERS
SUPPLY AIR TO HOUSE
RETURN AIR FROM COLLECTOR
AIR PLENUM
4
1.
AIR COLLECTOR
STORAGE CONTAINER
CONVENTIONAL FURNACE
SUPPLY AIR TO COLLECTOR
AIR PLENUM
RETURN AIR FROM HOUSE
CENTRIFUGAL FAN
3.
FILTER
2.
MOTOR OPERATED DAMPERS

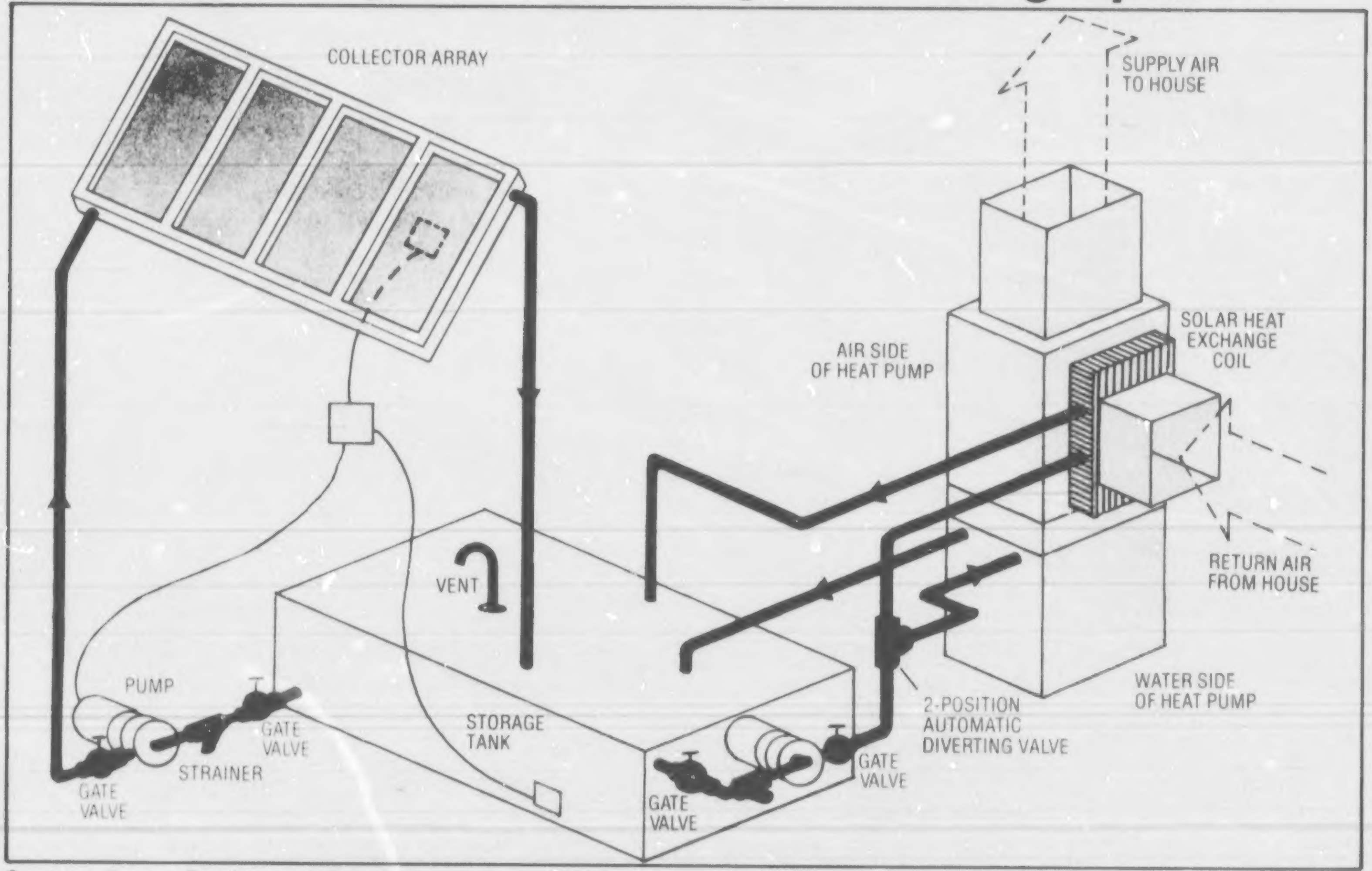
Courtesy Copper Development Association Inc.

Water Collection, Water Storage, Air-to-Air Heat Pump Distribution Space Heating System


COLLECTOR ARRAY
SUPPLY AIR TO HOUSE
OUTDOOR HEAT PUMP
SOLAR HEAT EXCHANGE COIL
VENT
RETURN AIR FROM HOUSE
PUMP
GATE VALVE
STRAINER
GATE VALVE
STORAGE TANK
GATE VALVE
GATE VALVE

Courtesy Copper Development Association Inc.

Water Collection, Water Storage, Water-to-Air Heat Pump Distribution Space Heating System


COLLECTOR ARRAY
SUPPLY AIR TO HOUSE
SOLAR HEAT EXCHANGE COIL
AIR SIDE OF HEAT PUMP
RETURN AIR FROM HOUSE
VENT
PUMP
GATE VALVE
STRAINER
GATE VALVE
STORAGE TANK
GATE VALVE
GATE VALVE
2-POSITION AUTOMATIC DIVERTING VALVE
WATER SIDE OF HEAT PUMP

Courtesy Copper Development Association Inc.

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

ASSIGNMENT SHEET #1--SOLVE PROBLEMS CONCERNING SOLAR DOMESTIC WATER HEATING SYSTEMS

A. What would be the least expensive solar domestic water heating system in a situation where hot water demands are medium, as opposed to high, and in a region where temperatures do not reach the freezing point?

Answer ____

B. What can be added to collector water to provide low-temperature protection in a solar domestic hot water heating system employing pumped circulation with a heat exchanger?

Answer ____

C. In a solar domestic hot water heating system that employs pumped circulation with freeze control, antifreeze cannot be used; how is freeze protection provided?

Answer ____

D. Single storage solar domestic hot water tanks are practical because they provide both solar and auxiliary storage in the same tank, but what precaution should be taken when planning such a system?

Answer ____

E. Certain configurations of dual solar domestic hot water tanks allow only relatively cold water to circulate through the collector; does this afford higher or lower collector efficiency?

Answer ____

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

ASSIGNMENT SHEET #2--SOLVE PROBLEMS CONCERNING SOLAR SPACE HEATING SYSTEMS

A. Of the several available solar space heating system designs, which system has found wide acceptance because it is simple to operate and control?

Answer ____________________

B. A heat pump has the capability of extracting heat from a cooler source and increasing it to a higher temperature; how does this capability affect a water collection, water storage, heat pump distribution space heating system?

Answer ____________________

C. Where are radiant panels most frequently installed when they are used in a water collection, water storage, water distribution space heating system?

Answer ____________________

D. What happens in an air collection, solid material storage, air distribution space heating system when the heating load demands cannot be met by the solar system?

Answer ____________________

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

A. A thermo-syphon system

B. Antifreeze

C. By pumping water through the system with a rate of flow high enough to prevent freezing

D. A large tank should be selected

E. Higher efficiency

Assignment Sheet #2

A. A water collection, water storage, air distribution system

B. The heat pump can extract useful heat from the solar storage system even when the temperature has fallen below room temperature

C. Slab floors

D. The auxiliary heating system comes on

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

JOB SHEET #1--CONSTRUCT A WORKING MODEL SOLAR WATER HEATER

I. Tools and materials

A. 1 shallow cardboard box

B. 1 sheet of glass large enough to cover the box

C. 20 feet of black rubber tubing

D. 1 ring stand

E. 1 large clamp

F. 1 condensation column

G. 1 pinch-cock

H. 1 Celsius thermometer

I. 1 50 milliliter (ml) beaker

J. 1 cork stopper

K. 1 funnel

L. 1 can of flat black paint and a paintbrush

M. Paint thinner and a clean cloth

(NOTE: The ring stand, clamp, condensation column, pinch-cock, beaker, stopper, and funnel should be available in the chemistry department at your local high school.)

II. Procedure

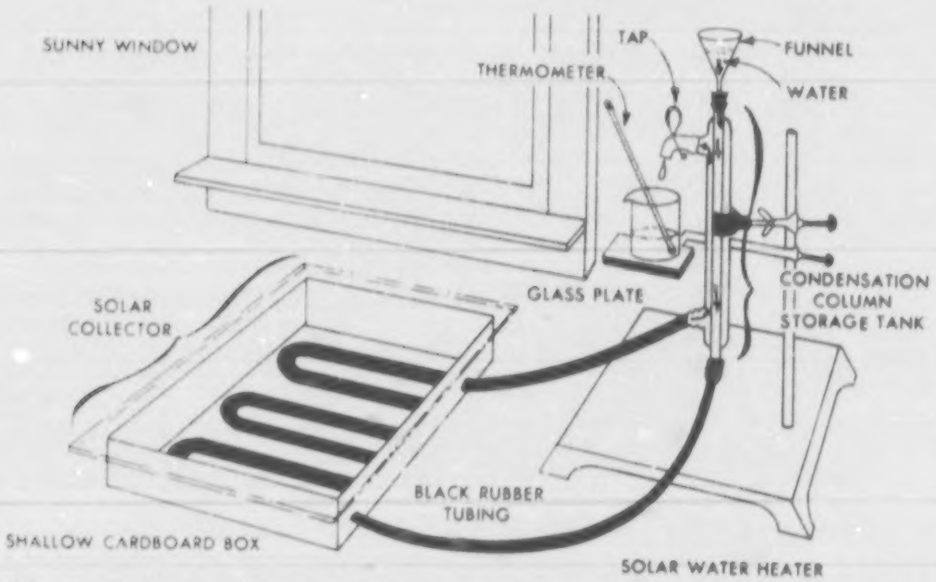
A. Assemble the apparatus for your solar water heater according to the diagram in Figure 1

JOB SHEET #1

B. Fill the entire unit with water (Figure 1)

(NOTE: Be sure the tubing, combination condensation column, and storage tank are completely filled.)

FIGURE 1


SUNNY WINDOW
TAP
FUNNEL
THERMOMETER
WATER
GLASS PLATE
CONDENSATION || COLUMN STORAGE TANK
SOLAR COLLECTOR
BLACK RUBBER TUBING
SHALLOW CARDBOARD BOX
SOLAR WATER HEATER

Courtesy U.S. Department of Energy

C. Drain off 50 ml of water from the tap and record the temperature on the data chart that accompanies this job sheet

D. Pour the water back into the funnel

E. Place your cardboard box solar collector in the sun and record the temperature of the water each minute for a period of 20 minutes

(NOTE: This means you will have to draw a water sample from the system for each check, but be sure to pour each sample back into the system.)

F. Record your data on the data chart

G. Drain the entire system

H. Paint the cardboard box black and allow it to dry

I. Clean the paintbrush while you are waiting for the paint to dry

J. Repeat steps B through F with the black cardboard box solar collector

JOB SHEET #1

DATA CHART

UNPAINTED BOX: INITIAL WATER TEMPERATURE __________

MINUTE #	TEMP. READING	MINUTE #	TEMP. READING
1		11	
2		12	
3		13	
4		14	
5		15	
6		16	
7		17	
8		18	
9		19	
10		20	

PAINTED BOX: INITIAL WATER TEMPERATURE __________

MINUTE #	TEMP. READING	MINUTE #	TEMP. READING
1		11	
2		12	
3		13	
4		14	
5		15	
6		16	
7		17	
8		18	
9		19	
10		20	

JOB SHEET #1

K. Record your data on the data chart

L. Drain the entire system

M. Return tools and materials to proper storage area

N. Answer the following questions:

1. Why should a *black* rubber tube be used in this activity?

   ____

2. How did painting the collector box black affect the temperature of the water?

   ____

   ____

3. What part of the system would be the same as the cold water supply pipe in your home hot water unit? ______________________________

   ____

4. The apparatus you've been working with has been termed "a solar water heater"; could it also be called a solar system? ______________________

5. Explain your answer to question 4. ______________________

   ____

6. List at least two things you could do to improve the efficiency of the solar collector you've been working with.

   ____

   ____

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

NAME ________________________________

TEST

1. Match the terms on the right with their correct definitions.

______a. Highly mineralized local water supplies that have high levels of dissolved sulfates and chlorides and high PH values

______b. Domestic hot water

______c. The circulation of water between a tank and a collector maintained by the natural convection currents that are set up when water is heated

______d. A device that absorbs heat and then releases it to complete the heat transfer process

______e. Containing poison

______f. Free of poison

______g. A pipe configuration designed to complete a liquid flow from one given point to another with interconnections among components in a system

______h. A valve which mechanically or electronically starts, stops, or diverts flow in a system

______i. A device which functions as a thermostat to detect changes in temperature; its on-off functions can be set for minimum low or maximum high temperatures

______j. A valve which permits flow in one direction only and prevents flow back to the source

______k. Working side by side or together

______l. A standby or backup storage facility that permits storage of hot water that exceeds the capacity of the prime or system storage facility

______m. A standby or backup gas or electric heating system programmed to automatically maintain heating load requirements when the solar system fails to meet the required load demands

1. Auxiliary heat
2. Corrosion
3. PH
4. Nontoxic
5. Tandem
6. Aggressive water
7. Heat exchanger
8. Damper
9. Open system
10. DHW
11. Toxic
12. One-way check valve
13. Sensor

______ n. Body which is capable of accepting, storing, and releasing heat

______ o. The eating away or wearing away of metals, especially metals in contact with chemicals

______ p. Any two metals that have different properties

______ q. An electro-chemical reaction that causes deterioration when two dissimilar metals come in contact

______ r. An electric insulator used to control electrolysis at points where dissimilar metals meet

______ s. A solar system into which no air penetrates or from which no air can be expelled

______ t. A solar system into which air can penetrate or from which air can be expelled for drain-down or to create a syphon effect

______ u. A symbol for the degree of acidity or alkalinity of a solution; PH is measured on a scale of 0, indicating highest acidity, to 14, indicating highest alkalinity

______ v. The tendency of certain insulating materials to release elements of their original composition, especially when exposed to high temperatures

______ w. A mechanical device, sometimes electronically activated, to stop or moderate flow within a system

14. Outgassing
15. Thermo-syphon
16. Loop
17. Closed syphon
18. Solenoid
19. Electrolysis
20. Auxiliary storage
21. Heat sink
22. Dielectric
23. Dissimilar metals

2. Complete the following list of statements concerning characteristics of a thermo-syphon DHW system.

   a. Most basic of ______________________________ heating systems

   b. Circulation of water between tank and collector is maintained by natural convection currents set up when water is heated

   c. Requires no ______________________________

   d. When the water in the solar collector becomes hotter than the water in the storage tank, it rises to the tank as the colder tank water drops into the collector supply line

   e. When no water is being run at a tap, circulation will continue until tank and collector temperature are ___________________________

   f. Rate of flow ____________________________ be controlled

   g. Difficult to provide freeze protection, and system is therefore most appropriate for regions that do not reach freezing temperatures

3. Circle the words which best complete the following statements concerning characteristics of a pumped circulation domestic hot water system with heat exchanger.

   a. (Domestic, Collector) water is pumped through a closed pipe loop incorporating a heat exchanger which is immersed in a storage tank

   b. The closed collector pipe loop must have a/an (expansion, storage) tank and a separate pressure relief valve in addition to the valve on the tank

   c. Because collected heat must be transferred through a heat exchanger, the collection fluid must be (hotter, cooler); this makes the system somewhat less efficient than one in which domestic water circulates directly through the collector

   d. A (relief, check) valve in the collector return prevents migration of heat from tank to collector by thermo-syphon action on cold nights

   e. Because collector water and domestic water do not intermingle, an antifreeze solution can be added to the (domestic, collector) water for low-temperature protection

4. Select true statements concerning characteristics of a pumped circulation domestic hot water system with freeze control by placing an "X" in the appropriate blanks.

   ______a. System employs a heat exchanger but does not use a heat pump

   ______b. Collector circuit is not sealed off from stored water, and antifreeze cannot be used

   ______c. Freeze protection is provided by pumping water through the system with a rate of flow high enough to prevent freezing

   ______d. A two-way solenoid valve is the key control element in a pumped circulation system

   ______e. During normal operation, the solenoid valve allows water to circulate freely between tank and collector

   ______f. During normal operation, cold water is admitted to the system unless a hot water tap is opened in the building, in which case makeup water enters from the supply source

   ______g. In freezing temperatures, the solenoid valve automatically opens in the storage tank and diverts water from the collector into a dry well or sump, setting up a constant flow of water from the source through the collector circuit and into the sump

5. Select true statements concerning characteristics of a pumped circulation domestic hot water system with draindown by placing an "X" in the appropriate blanks.

   ______a. System incorporates a circulating pump for collector water, but does not employ a heat exchanger

   ______b. System employs a temperature sensor affixed to the bottom of the circulating pump ______c. When the sensor detects a drop to about 40°F, it initiates closing of the motorized valve in the collector supply

______d. When the motorized valve reaches a fully closed position, it trips an end switch which in turn trips the solenoids of only the dump valve and not the air intake valve

______e. Water then drains freely from the collector circuit and out of the system

______f. Pressurized source water is prevented from flowing to the collector by means of a motorized valve in the supply line and a one-way check valve in the return line

______g. When the absorber plate temperature rises to a preset difference above storage, the motorized valve begins to open, the circulating pump restarts, and the dump valve and inlet vclve open

______h. As the collector circuit refills, trapped air is relieved through the automatic vent and normal circulation of collector water is resumed

6. List two arrangements for domestic hot water storage tanks.

   a. ____

   b. ____

7. Complete the following list of statements concerning characteristics of dual domestic hot water tanks.

   a. A larger tank is connected to the collector loop and stores hot water from the ______________________

   b. In tandem with the larger tank is a conventional water heater with a fossil-fuel burner or an ______________________________

   c. The ______________________________ of the solar storage tank is connected to the cold or inlet line of the conventional heater

   d. Any demand for hot water causes the source water pressure to force water through the solar storage tank, through the conventional tank, and out to a hot water tap

   e. When the ________________________ water is warm enough, it will move through the conventional tank without affecting the thermostat in the conventional tank and without requiring additional heat

   f. Should the conventional tank water drop below a preset temperature, it will cause the thermostat in the conventional tank to trip and energize the conventional water heater burner or ________________________

   g. This configuration allows only the relatively cold water to circulate through the collector, and this permits the collector to function at ________________

8. Circle the words which best complete the following statements concerning characteristics of a single storage domestic hot water tank.

    a. (Can, Cannot) provide both solar and auxiliary storage in the same tank

    b. When this system is used, a (small, large) tank should be selected

    c. The thermostat of the auxiliary fuel input should be set to maintain a tank temperature of about (100-110°F, 110-120°F)

    d. Because the lowest temperature of water that can be circulated back through the collector is 110°F, collector efficiency is (increased, lowered)

9. Select true statements concerning characteristics of a combined solar space and domestic hot water system by placing an "X" in the appropriate blanks.

    ______a. Water is heated and stored in a solar storage tank

    ______b. Makeup water for hot water supply passes through a heat exchanger in the solar storage tank

    ______c. If the solar storage tank temperature is high enough, cold domestic makeup water passing through will pick up sufficient heat to avoid drawing energy from the domestic water heater

    ______d. When the temperature of the domestic water tank goes above the storage tank temperature, the domestic water is pumped through the heat exchanger, transferring whatever heat is available

    ______e. An auxiliary heat supply cannot be programmed to supplement DHW requirements

10. Complete the following list of statements concerning characteristics of a water collection, water storage, air distribution space heating system.

    a. These systems have found wide acceptance because they are ____________________ ______________________________

    b. The circulating pump in the collector loop operates whenever collector temperature is ________________ than the temperature of the storage tank water by a preset amount

    c. When the pump stops, water in the collectors and pipe lines drains into the ____________________________

    d. To permit the automatic draining process, the return pipe must be coupled to the tank in such a fashion that the end of the pipe is kept ________________ ____________________ of the stored water or the pipe must be vented by some other means

    e. When the building thermostat calls for heat, a pump circulates stored water through the heat exchanger coil in the return air duct upstream of the __________ _________________

f. As water is being circulated through the heat exchanger, the furnace fan begins to draw air through the heat exchanger coil and forces the warmed air into the building

g. As long as the coil continues to maintain supply air temperature high enough, the furnace heating element remains off, but when ______________________ falls short of preset temperature settings, the furnace comes on to furnish supplementary heat

11. Distinguish between a series configuration and a parallel configuration in water collection, water storage, water distribution space heating systems by placing an "X" next to the descriptions of a series configuration.

______ a. Highly suited for fin tube and radiant panel installations

______ b. One configuration for this system is that heat can be supplied by either the solar system or the auxiliary boiler

______ c. Another configuration for this system is that heat can be supplied by both the solar system and the auxiliary boiler

______ d. When the solar storage tank is hot enough to supply the heating load, water is pumped from the storage tank through the finned tubes and bypasses the boiler

______ e. If the storage tank is not hot enough to supply the heating load completely, water is pumped through the boiler and then into the finned tubes, bypassing the storage tank

______ f. If the heating requirement can be supplied by the water from the solar tank, the auxiliary boiler does not operate

______ g. When more heat is required than the solar system can supply alone, the boiler kicks in to supplement the solar heat

______ h. Permits lower temperature water in the solar system to be used to supply a portion of the heating load and actually contributes to higher collector efficiency and more usable solar energy

12. Complete the following list of ways radiant panels are used in water collection, water storage, water distribution space heating systems.

a. Radiant panel heating systems employ copper tubes embedded in concrete floor slabs and in wall and ceiling construction

b. Floor installations are the most common with copper coils embedded in concrete with ______________________ or more of concrete above the tubes and never less than an inch of concrete below the tubes

c. Ceiling and wall panels are usually embedded in ______________________

d. Wall panel installations require ______________________ to reduce heat loss to the outside

13. Select true statements concerning characteristics of an air collection, solid material storage, air distribution space heating system.

______ a. When heat is available for collection, but there is no heat demand in the house, the collector circulation fan begins to draw air down through the storage container

______ b. Motor operated damper number 3 is closed whenever the collector fan is operating and open at all other times

______ c. The bottom portion of the storage container contents will heat first, and the heat will extend upward as more energy is collected

______ d. When no heat is being collected, but is called for in the building, the centrifugal fan in the auxiliary heating system begins operation and signals dampers 1 and 2 to open

______ e. Return air is drawn upward through the storage, exits at maximum temperature, and is circulated through the building

______ f. When the heating load cannot be supplied by the solar system, the auxiliary heating system comes on

______ g. When there is a simultaneous collection of energy and demand for heat by a building, motor operated damper 4 is open

______ h. Air is circulated directly from the collector to the building

14. Complete the following list of characteristics of water collection, water storage, heat pump distribution space heating systems.

a. The electrically driven heat pump enhances the flexibility and efficiency of ______________________________

b. A heat pump has the capability of extracting heat from a cooler source and increasing it to a higher temperature, thereby increasing the ______________________________

c. A heat pump can extract useful heat from the solar storage system even when the temperature has ______________________________ room temperature

15. Distinguish between an air-to-air heat pump and a water-to-air heat pump function in a solar space heating system by placing an "X" next to the function of an air-to-air heat pump.

______ a. When heating is required, the heat pump extracts heat from the storage water, increases its temperature, and warms the room air

______ b. When heating is required, the heat pump extracts heat from one air source (usually the outside air), increases its temperature, and warms the room air

16. Select true statements concerning steps in the operation of an air-to-air heat pump in a solar heating system by placing an "X" in the appropriate blanks.

______ a. All solar heating is done directly from storage without the aid of the heat pump, but the heat pump fan is used to circulate room air over the heat exchange coil ______b. If heat available from solar storage is insufficient, the heat pump begins to operate, supplying additional heat to the air

______c. Although this does not permit stored solar energy to be used below the space temperature, it greatly reduces operational time of the heat pump and saves much electricity that would otherwise be used to operate the heat pump compressor

17. Select true statements concerning steps in the operation of a water-to-air heat pump in a solar heating system by placing an "X" in the appropriate blanks.

______a. When the solar storage tank temperature falls below a preset point (usually 90°F), storage is used directly for space heating with the heat pump fan circulating the room air over the solar water coil

______b. When the storage tank temperature is over the temperature needed for heating, the control valve changes position and circulates the storage water into the heat pump

______c. When the water flow to the heat pump has been proven by a flow switch, the heat pump compressor begins to operate extracting heat from the water and increasing its temperature; it is then used for warming room air

______d. This procedure continues until the heating load has been satisfied or storage tank temperature drops to the lower operating limits of the heat pump (usually about 60°F)

______e. Sometimes, other water supplies of appropriate temperature can be used when usable water in the solar storage tank has been exhausted

______f. An auxiliary heat supply is usually required with a water-to-air heat pump solar system

18. Circle the words which best complete the following statements concerning design considerations for piping systems.

a. (Corrosion, Freezing) is the biggest enemy of piping systems and other solar components

b. It is imperative, from a corrosion standpoint, that the fluid passages in the (collector, absorber plate) be compatible with the materials used for piping, storage tank, pump, and valve bodies

c. All (pumps, piping) should be pitched from the high point of the system to insure complete drainage when necessary

d. In systems with drainage as freeze protection, the piping should be pitched at a minimum of (1/2, 1/8) inch per 1 foot of run to insure that fluid will drain completely

e. Start up of all liquid-carrying systems should include a flushing operation to remove (water and air, dirt and debris) accumulated during fabrication and installation

19. Select true statements concerning design considerations for corrosion protection by placing an "X" in the appropriate blanks.

_____a. Corrosion protection has three major concerns in metal collector systems:

1) Corrosion between dissimilar metals

2) Use of corrosive liquids

3) Presence of air in the system

_____b. When dissimilar metals are used in the presence of moisture, corrosion can occur; this is true even of copper when used with another metal

_____c. In a solar system with a circulating fluid, it is sufficient simply to use dielectric fittings to separate dissimilar metals and control electrolysis

_____d. Although it is difficult to exclude copper valves and pump impellers from collector systems, as a general rule, it is best to mix metals

20. List four other considerations for corrosion protection.

a. ____

____

b. ____

____

c. ____

____

d. ____

____

21. Solve the following problem concerning design considerations for collector cover glazing. Additional layers of cover glazing reduce heat loss in a collector; why not keep adding glazing to make the collector even more efficient?

____

____

22. Complete the following list of statements concerning requirements for absorber plate insulation.

a. Since absorber plates frequently reach temperatures of more than 200°F, they must be insulated to ________________________ from the plate

b. The back of the collector is typically insulated with a ____________ thick fiberglass blanket

c. Most ______________________________ insulation currently available undergoes volumetric expansion at temperatures of 250°F and should be used with care, if at all

d. Other insulations have problems with the outgassing of volatile elements which can lead to corrosion and ______________________________

e. Insulation selected should be evaluated according to application needs

23. Solve the following problem concerning high temperature protection and its applications: When cooler fluid is pumped into a collector in a condition of stagnation, what usually happens?

____

____

24. Complete the following list of statements concerning rules of thumb for circulating pumps and solar system controls.

a. Pumps ordinarily selected for residential and small solar applications should be centrifugal types with mechanical shaft seals or ______________________

b. Pumps may be close-coupled, in-line, or ______________________

c. Pump should have a proper combination of ______________________ and lift characteristics for the application

d. In ______________________, pumps must have sufficient lifting capacity to raise water from the storage tank to the top of the collector

e. In most small solar systems, the pumps will not exceed 1/4 to 1/3 horsepower and may be as small as 1/6 to 1/20 horsepower in ______________________

f. When centrifugal pumps are used, it is essential that they operate with a net positive suction head

g. The ______________________ in the collector loop is normally started or stopped by means of a differential temperature control which actuates the collector pump when the collector temperature is higher than the tank water temperature, and shuts the collector pump off when the collector water temperature approaches the tank temperature

25. Solve problems concerning solar domestic water heating systems.

26. Solve problems concerning solar space heating systems.

27. Demonstrate the ability to construct a working model solar water heater.

(NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

ACTIVE SOLAR HEATING SYSTEMS
UNIT II

ANSWERS TO TEST

1.

a.	6	g.	16	m.	1	s.	17
b.	10	h.	18	n.	21	t.	9
c.	15	i.	13	o.	2	u.	3
d.	7	j.	12	p.	23	v.	14
e.	11	k.	5	q.	19	w.	8
f.	4	l.	20	r.	22		

2. a. Solar water
   c. Heat exchanger
   e. Equalized
   f. Cannot

3. a. Collector
   b. Expansion
   c. Hotter
   d. Check
   e. Collector

4. b, c, e

5. a, c, e, f, h

6. Any two of the following:
   a. Dual solar and conventional tanks
   b. Single storage tanks
   c. Combined solar space and DHW heating systems

7. a. Collector
   b. Electric heating element
   c. Outlet pipe
   e. Solar-heated
   f. Electrode
   g. A higher efficiency

8. a. Can
   b. Large
   c. 110-120°F
   d. Lowered

9. a, b, c

10. a. Simple to operate and control
    b. Higher
    c. Storage tank
    d. Above the level
    e. Furnace
    g. Solar supplied heat

11. a, b, d, e

12. b. One inch
    c. Plaster
    d. Heavy insulation

13. a, d, e, f, h

14. a. Solar systems
    b. Thermal gradient
    c. Fallen below

15. b

16. a, b, c

17. c, d, f

18. a. Corrosion
    b. Absorber plate
    c. Piping
    d. 1/8
    e. Dirt and debris

19. a, b

20. Any four of the following:
    a. Check the local water supply for PH level
    b. A trouble free history of copper plumbing in the locality can usually be taken as evidence that the water is not aggressive to copper, but it may be aggressive to other metals
    c. When there is a question concerning the presence of aggressive water, the water should be chemically analyzed, and a treatment engineer should be consulted to prescribe ways to make and keep the water nonaggressive
    d. When antifreeze or special heat transfer fluids are added to the water, it increases the potential for corrosion
    e. Anti-freezes which are propylene glycol (nontoxic) or ethylene glycol (toxic) based are the two major types of anti-freeze used with water in solar collectors
    f. Propylene glycol is claimed to be nontoxic and should be used in DHW systems unless a double walled heat exchanger is employed
    g. Anti-freeze solutions usually require the addition of corrosion inhibitors and buffers for PH, and all anti-freeze solutions should be monitored and replenished as required

21. There is a point where additional glazing actually diminishes collector efficiency

22. a. Maximize energy collection
    b. 3 to 4-inch
    c. Foamed urethane
    d. Other collectable problems

23. This usually results in thermal shock which can cause the collector to buckle and the glazing to break

24. a. Totally sealed units
    b. Base-mounted
    c. Flow rate
    d. Open systems
    e. Closed systems
    g. Circulating pump

25. Evaluated to the satisfaction of the instructor

26. Evaluated to the satisfaction of the instructor

27. Performance skills evaluated to the satisfaction of the instructor

LOAD CALCULATIONS AND SOLAR COOLING
UNIT III

UNIT OBJECTIVE

After completion of this unit, the student should be able to solve a problem concerning considerations for establishing heat requirements for solar water heating, discuss the concept of degree days, list the procedure for sizing a solar collector, and discuss basic concepts of solar cooling with absorption systems. The student should also be able to complete a sun-chart worksheet for a specific solar application and size a solar collector. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to load calculations and solar cooling with their correct definitions.
2. Solve a problem concerning considerations for establishing heat requirements for solar water heating.
3. Solve a problem concerning the concept of degree days and its formula.
4. Solve a problem concerning the concept of the degree day adjustment factor and its applications.
5. Solve a problem concerning the sun chart worksheet and its applications.
6. Complete a list of statements concerning the procedure for collector sizing.
7. Select true statements concerning rules of thumb for solar refrigeration systems.
8. Complete a list of statements concerning basic concepts of solar cooling with absorption systems.
9. Match types of lithium-bromide-water units with their characteristics.
10. Select true statements concerning operating principles of an absorption air conditioner.
11. Select true statements concerning system flow in a water chiller application.
12. Solve a problem concerning evaporative cooling with rock-bed storage.
13. Complete a sun-chart worksheet for a specific solar application.
14. Size a solar collector for a combination DHW and space heating solar system.

LOAD CALCULATIONS AND SOLAR COOLING
UNIT III

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information and assignment sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Review basic elements of heating and cooling load calculations.

(NOTE: This information is available in *Manual J, Load Calculation for Residential Winter and Summer Air Conditioning*; check with a local air conditioning contractor to obtain a copy, or it may be ordered from The Air-Conditioning Contractors of America, 1228 17th St. N. W., Washington, D.C. 20036; the *ASHRAE Handbook of Fundamentals* is another source for information on load calculations, or the materials in Unit VI, "Residential Heat Loss and Heat Gain," *Air Conditioning and Refrigeration, Book III,* as published by the Mid-America Vocational Curriculum Consortium, will serve the purpose well.)

VII. Invite a representative from a local gas or electric utility to talk to the class concerning calculations for heating and cooling loads; most utilities use computerized load calculations, and it would be especially effective if the utility representative could present a computerized load calculation that would provide the students with additional information and assistance with the assignment sheets in this unit.

VIII. Read the assignment sheets carefully, and select a model home that students can use to adequately calculate heating loads for a typical solar application in your specific locale.

IX. Prepare a chart of solar information pertinent to your area; it should include latitude, degree day information, design temperature for both heating and cooling, a solar insolation chart, and prevailing winter and summer winds.

X. Locate a business or residence in your area that is using a solar cooling system, and invite the person most familiar with the system to talk to the class about its design, performance, and maintenance.

XI. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

   A. Objective sheet

   B. Information sheet

   C. Transparency masters

      1. TM 1--Absorption Air Conditioner

      2. TM 2--Flow Schematic of a Water Chiller Operation

      3. TM 3--Evaporative Cooling with Rock-Bed Storage

   D. Assignment sheets

      1. Assignment Sheet #1--Complete a Sun-Chart Worksheet for a Specific Solar Application

      2. Assignment Sheet #2--Size a Solar Collector for a Combination DHW and Space Heating Solar System

   E. Test

   F. Answers to test

II. References:

   A. *Solar Energy Systems.* New York, NY 10174: Copper Development Association, Inc., 1979.

   B. Solar Energy Applications Laboratory, Colorado State University. *Solar Heating and Cooling of Residential Buildings, Sizing, Installation and Operation of Systems.* Washington, D.C. 20402: U.S. Department of Commerce, 1977.

   C. *Solar Energy Project, Text.* Washington, D.C. 20545: U.S. Department of Energy, 1979.

   D. *Solar Energy Project, Reader.* Washington, D.C. 20545: U.S. Department of Energy, 1979.

LOAD CALCULATIONS AND SOLAR COOLING
UNIT III

INFORMATION SHEET

I. Terms and definitions

A. Btu--British thermal unit; the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit

B. Btuh--British thermal units per hour; unit used to express hourly heat flow

C. Dry-bulb temperature--The air temperature as measured by an ordinary thermometer

D. Wet-bulb temperature--The air temperature as measured by a thermometer whose bulb is covered with a wet cloth or wet wick and moved in air that has a velocity of one thousand feet per minute

E. Heat loss--The amount of heat lost through all building surfaces, walls, floors, doors, and windows exposed to outdoors or to adjoining spaces with different temperatures

F. Heat gain--The amount of heat gained through all building surfaces, walls, floors, doors, and windows exposed to outdoors or from adjoining spaces with different temperatures

G. Load--The total heat loss and heat gain of a structure expressed in Btuh; this calculation is used to size heating and cooling equipment

H. Ventilation--Controlled air brought into a structure

I. Infiltration--Uncontrolled air that leaks into a structure

J. Humidity--The amount of water vapor or moisture that is present in the atmosphere or any material

K. Relative humidity--The percentage of moisture in the air compared to the total amount of moisture the air could hold at the same temperature and barometric pressure

L. Psychometrics--The science of measuring and changing the properties of air

M. Hydronics--The science of heating and cooling with liquids

N. Nomogram--A chart which can be used with a straightedge to determine the square footage requirements of a collector

O. Refrigerant--A substance used in refrigerating mechanisms to absorb heat in the evaporator

P. Absorbent--A liquid which combines chemically with a refrigerant and causes heat to be released in the process of combination

INFORMATION SHEET

Q. R-value--The rating given to a material's ability to resist heat transfer

R. Cfm--Cubic feet per minute

S. Ton of refrigeration--A refrigerating effect equal to 12,000 Btuh

T. Chiller--The component in an absorption cooling unit which absorbs heat from the circulating water supply

II. Considerations for establishing heat requirements for solar water heating

A. Hot water consumption is the major factor influencing annual heat requirements

B. The amount of heat required to produce hot water depends on

1. Number of gallons of hot water consumed daily

2. Inlet temperature of the cold water supply

3. Desired discharge temperature at the fixtures

C. Deep wells produce water at a relatively constant temperature, but water from shallow wells, lakes, rivers, and reservoirs varies with changing air temperature throughout the year (Figure 1)

FIGURE 1

		J	F	M	A	M	J	J	A	S	O	N	D
Albuquerque	W	62	62	62	62	62	62	62	62	62	62	62	62
Boston	Re	32	36	39	52	58	71	74	67	60	56	48	45
Chicago	L	32	32	34	42	51	57	65	67	62	57	45	35
Denver	Ri	39	40	43	49	55	60	63	64	63	56	45	37
Fort Worth	L	46	49	57	70	75	81	79	83	81	72	56	46
Los Angeles	Ri	50	50	54	55	63	70	73	73	72	68	57	52
Las Vegas	L.W	57	64	68	71	77	85	87	86	78	70	65	57
Miami	W	70	70	70	70	70	70	70	70	70	70	70	70
Nashville	Ri	46	46	53	63	66	69	71	75	75	71	58	53
New York	Re	36	35	36	39	47	54	58	60	61	57	48	45
Phoenix	Ri,Re,W	48	48	50	52	57	59	63	75	79	69	59	54
Salt Lake C.	W,C	35	37	38	41	43	47	53	52	48	43	38	37
Seattle	Ri	43	42	46	51	56	61	65	66	65	58	52	44
Washington	Ri	42	42	52	56	63	67	67	78	79	68	55	46

Source Data From Handbook of Air Conditioning System Design, p. 5-41 through 5-46, McGraw Hill Book Company, New York (1965). Abbreviations: C—Creek, L—Lake, Re—Reservoir, Ri—River, W—Well

Courtesy Copper Development Association Inc.

INFORMATION SHEET

D. The formula for determining Btu requirements for hot water is: Desired discharge temperature minus inlet temperature of cold water supply times 8.33 (it takes 8.33 Btu to raise one gallon of water 1°F) times the number of gallons of hot water consumed

(NOTE: The chart in Figure 2 shows how the above formula would work in determining hot water requirements for a family of four in Nashville, Tennessee; the desired discharge temperature is 135°F and the water consumption is estimated to be 91 gallons per day.)

FIGURE 2

Example: Family of Four—
Nashville, Tennessee
High Consumption—
91 Gallons/Day

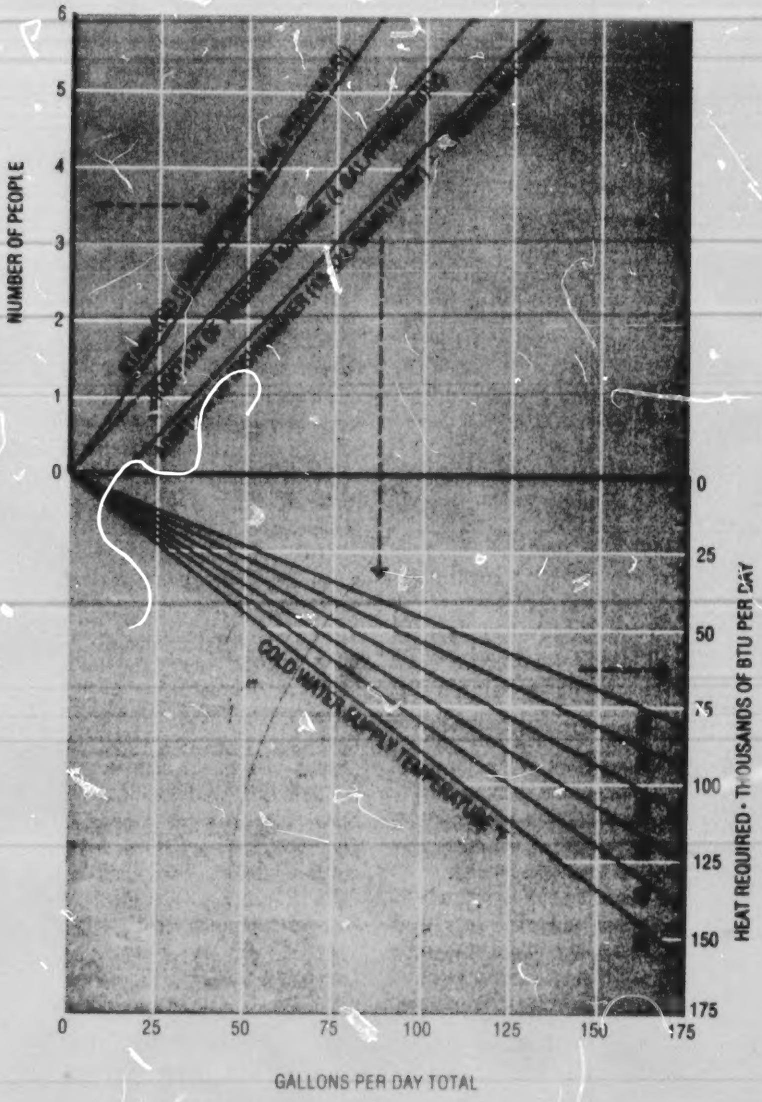
MONTH	COLD WATER TEMP.	HEAT REQUIREMENTS (BTU/DAY)
January	46	67,500
February	46	67,500
March	53	62,200
April	63	54,600
May	66	52,300
June	69	50,000
July	71	48,500
August	75	45,500
September	75	45,500
October	71	48,500
November	58	58,400
December	53	62,200

Courtesy Copper Development Association Inc.

INFORMATION SHEET

E. Typically, a family of four consumes between 60 to 90 gallons of hot water daily, but the hot water consumption requirements can be arrived at for any latitude by interpolating between the cold water supply temperatures shown in Figure 1, the formula for arriving at Btu requirements given in item D, and by using the chart in Figure 3 to achieve a number of persons/gallons requirements figure

FIGURE 3



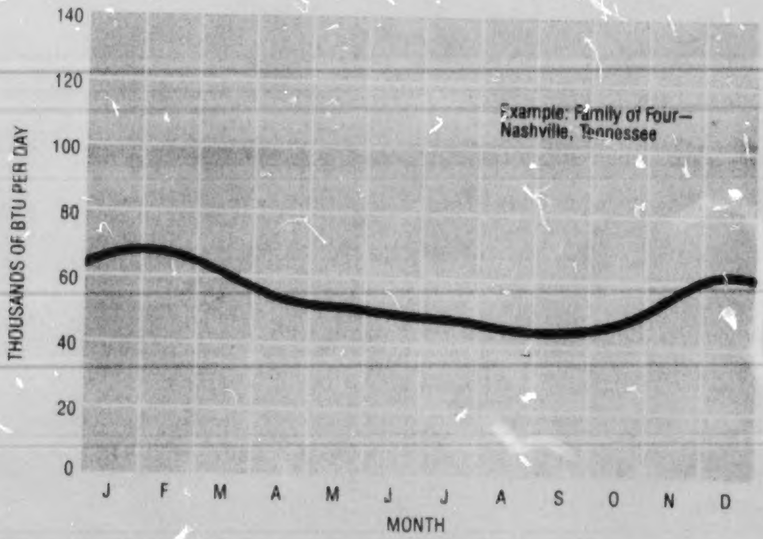
Courtesy Copper Development Association Inc.

INFORMATION SHEET

F. Calculations obtained by using the chart in Figure 3 can be checked by plotting a graph of the information; the graph should curve smoothly, and any sharp deviation in any month is a clue that an error exists (Figure 4)

(NOTE: The following graph reflects information previously noted for a family of four in Nashville, Tennessee.)

FIGURE 4



Courtesy Copper Development Association Inc.

III. The concept of degree days and its formula

A. Instead of using peak heating demands to determine heating requirements, the concept of degree days is used to determine average requirements

B. A degree day is a standard used to measure the heating season's mean temperature

C. The number of degree days in a calendar day is determined by the following formula: Subtract the day's mean temperature from 65°F

Example: If the mean temperature on a given day is 50°F, subtract 50°F from 65°F, and this yields 15 degree days for that specific calendar day

D. By adding the number of degree days for each day of the month, the average monthly conditions can be identified, and the average yearly conditions can be identified

(NOTE: Degree days charts for many locations in America and Canada are available from many sources; examples will be given later in this unit.)

INFORMATION SHEET

E. In general, a solar system should be considered for a residence only when the space heating demand has been limited to approximately 8 Btu per square foot per degree day or less

Example: Consider a home in Nashville, Tennessee, which loses 30,000 Btu per hour, while the outdoor temperature is 17°F; if this temperature exists for a 24-hour period, the building demand is 30,000 × 24 which is 720,000 Btu; since the design point temperature is 17°F (48 degree days per day), the house requires a net heat input of 15,000 Btu per degree day as shown below:

$$\frac{30{,}000\ \text{Btu/hr} \times 24\ \text{hrs}}{(65^\circ\text{F degree day base} - 17^\circ\text{F design point temp})} = \frac{15{,}000}{\text{Btu/DD}}$$

Assuming that the home's floor area is 2,000 square feet, the required heat input is 7.5 Btu per square foot per degree day; since this is less than the requirements of 8 Btu per square foot per degree day, this house is a good candidate for solar heating

F. Homes that exceed the minimum 8 Btu per square foot per degree day are not well suited for solar applications and the money would be better spent on insulation to reduce energy demands

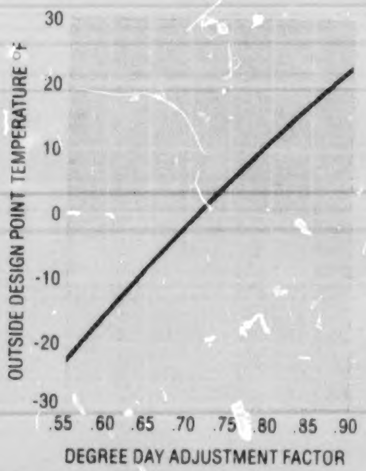
IV. The concept of the the degree day adjustment factor and its applications

A. Because structures absorb radiant heat through windows and other components, this actually lowers the building's heating requirements, but are not included in peak load calculations

INFORMATION SHEET

B. This adjustment is made by using a degree day adjustment factor as presented in the following chart (Figure 5)

FIGURE 5



The outside design point temperature is based on hourly average temperatures for each hour of a total year. The average hourly temperatures will be above the design point temperature 97½ percent of the year.

Courtesy Copper Development Association Inc.

C. Using the degree day adjustment factor is as simple as finding the outside design point temperature and tracing a line across the chart until it intersects the proper adjustment factor, which will always be less than 1.0; then, the average heat requirement calculated by standard measurement is multiplied by the degree day adjustment factor

INFORMATION SHEET

D. The heat load calculations for each month should be completed to include the degree day adjustment factor and prepared in a chart such as the one shown in Figure 6

FIGURE 6

Example: Nashville, Tennessee

Month	(BTU/Day)
January	322,500
February	296,700
March	213,000
April	81,270
May	16,550
June	0
July	0
August	0
September	12,900
October	65,750
November	212,850
December	304,600

Courtesy Copper Development Association Inc.

E. Add all the heating load requirements to the hot water load requirements to obtain the total heating requirements for the home

V. The sun-chart worksheet and its applications

A. The sun-chart worksheet is a simplified approach that permits rapid evaluation of heat loads and collector areas

(NOTE: The sun-chart worksheet was developed by the Copper Development Association, Inc., and when properly used, generates results equal to or slightly more conservative than results achieved by computer analysis; obviously, calculations cannot be guaranteed by the CDA, but when used properly, the sun-chart worksheet can be an effective planning tool.)

B. The simplification of calculations is accomplished by making the following assumptions about solar system characteristics:

1. The collector orientation is within 15 degrees of due south; applications that vary significantly from this should be calculated after adjustment factors from an orientation chart
2. Collectors with circulating liquids are used to carry collected energy to storage or load
3. Water storage capacity ranges from 1 1/2 to 2 gallons per square foot of collector array

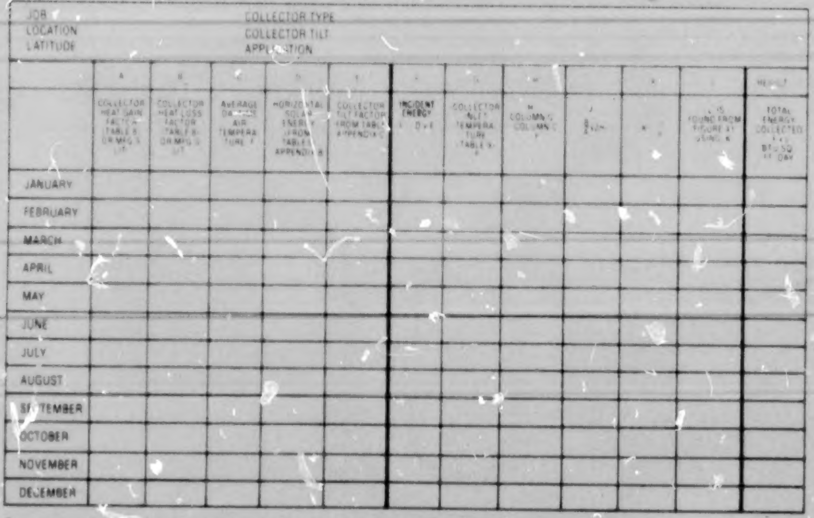
C. The designer begins by entering the first five column's (A through E) available data concerning the application (Figure 7)

INFORMATION SHEET

D. The designer then performs six mathematical operations using these basic data and enters the results in columns F through L (Figure 7)

E. A final multiplication yields data for the "Result" column on the far right; the average daily heat produced during each of the 12 months by one square foot of collector at a given tilt angle, operating at a specific temperature, and installed in a particular locality (Figure 7)

FIGURE 7



JOB

LOCATION

LATITUDE

COLLECTOR TYPE

COLLECTOR TILT

APPLICATION

	A	B	C	D	E	F	G	H	[illegible]	[illegible]	[illegible]	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG'S LIT	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG'S LIT	AVERAGE DAYTIME AIR TEMPERATURE F	HORIZONTAL SOLAR ENERGY (FROM TABLES APPENDIX B)	COLLECTOR TILT FACTOR FROM TABLE APPENDIX C	INCIDENT ENERGY D × E	COLLECTOR INLET TEMPERATURE (TABLE 9) F	COLUMN G − COLUMN C	[illegible]	[illegible]	IS FOUND FROM FIGURE [illegible] USING K	TOTAL ENERGY COLLECTED F × L BTU/SQ FT DAY
JANUARY												
FEBRUARY												
MARCH												
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER												

Courtesy Copper Development Association Inc.

F. Information from the worksheet is then used to properly size the solar collector

(NOTE: Step by step use of the CDA sun-chart worksheet is presented in Assignment Sheet #1.)

VI. Procedure for collector sizing

A. Once the rate of energy output from the collector has been established, the designer can proceed to find the collector area needed for a specific application

B. It is normally not economically practicable to size solar systems to handle 100 percent of the heating requirements

C. Collectors for DHW systems are usually sized to handle 70 to 80 percent of annual heating requirements

D. Collectors for combination DHW and space heating systems are usually sized to handle 60 to 70 percent of annual heating requirements

INFORMATION SHEET

E. As a rule of thumb, the correct percentages for sizing a collector can be established by:

1. Sizing a collector for a DHW system so that it supplies 100% of the heat requirement for the month of May

2. Sizing a collector for a combination system so that it supplies 100% of the heat requirement for the month of March

   (NOTE: The procedure for collector sizing is covered step by step in Assignment Sheet #2.)

VII. Rules of thumb for solar refrigeration systems

A. Since refrigeration systems affect cooling by removing heat from the air as it comes in contact with a cold, refrigerated surface, conventional vapor-compressor cooling systems using electric motors are adaptable to systems using solar energy

B. Absorption systems are not adaptable to systems using solar energy

C. For economic reasons, the absorption systems appear to be the most useable in solar systems

D. Absorption systems currently available include:

1. Lithium-bromide-water units

2. Water-ammonia absorption units

E. Lithium-bromide-water units are more commercially available than other types of units

VIII. Basic concepts of solar cooling with absorption systems

A. Absorption systems are similar in principle to an ordinary, electrically operated vapor-compression air conditioner

B. Instead of a refrigerant like Freon in a conventional air conditioner, inorganic refrigerants, such as water and ammonia, are used in an absorption machine together with an absorbent

C. An absorbent is a liquid which combines chemically with the refrigerant and releases heat from the fluid mixture in the combination process

D. In a lithium-bromide-water unit, water is the refrigerant and the lithium-bromide is the absorbent

E. In an ammonia-water unit, ammonia is the refrigerant and water is the absorbent

(NOTE: These units are normally used only for commercial applications.)

INFORMATION SHEET

IX. Types of lithium-bromide-water units and their characteristics

A. Air chiller--Cools air which contacts the cooling coils

B. Water chiller--Cools water which contacts the cooling coils

X. Operating principles of an absorption air conditioner (Transparency 1)

A. The cycle begins when water in the liquid mixture in the generator is boiled off and superheated with solar energy at a temperature between 170 and 210°F

B. The superheated water vapor passes from the generator to the condenser where it is cooled to about 100°F by the cooling water from an outdoor cooling tower

C. The vapor condenses to a liquid and is then revaporized through an expansion valve which cools the vapor-liquid mixture to a temperature of 40°F in the evaporator coils

D. The heat in the room air or water which is brought in contact with the evaporator is removed by the cooled refrigerant in the evaporator

E. The refrigerant then passes to the absorber where it recombines with the concentrated lithium-bromide solution from the generator at a temperature of about 100°F

F. In this recombination process, heat is released, and the heat is removed by the cooling water from the cooling tower

G. The dilute solution of lithium-bromide and water in the absorber flows by gravity, or is pumped back to the generator, and the cycle is repeated

H. Some lithium-bromide-water systems use a recouperator as a heat exchanger to make the system thermodynamically more efficient

XI. System flow in a water chiller application (Transparency 2)

A. The absorption chiller should be situated close to the hot water storage tank to minimize heat loss from the pipelines connected to the tank

B. Hot water from the top of the storage tank is pumped through the generator by pump (P-2) and returned to the bottom of the tank; note that the piping connection goes through the auxiliary boiler

C. When the temperature in the storage tank is insufficient to operate the absorption chiller, the auxiliary boiler is used to provide heat to the generator

D. When the auxiliary boiler is used, the three-way valve at the bottom of the auxiliary boiler circulates the return water only through the auxiliary boiler so that auxiliary energy is not used to heat the solar storage tank

INFORMATION SHEET

E. Pump size and head depend on the flow rate and pressure loss through the system and also the size and length of piping

F. A wet cooling tower is needed with the absorption chiller to discharge the heat from the condenser and the absorber to the atmosphere

(NOTE: Some smaller systems employ air to discharge heat from the condenser.)

G. The size of the cooling tower depends on the size of the absorption machine and the wet-bulb temperature of the ambient air

H. A pump (P-3) is needed to circulate the cooling water from the tower through the absorber and condenser of the absorption machine

I. Chilled water from the evaporator is circulated to the fan-coil unit to cool the air in the rooms

(NOTE: Operation of water-ammonia absorption units are similar to the lithium-bromide-water units except that operating temperatures are higher and a separator is inserted between the generator and condenser, but water-ammonia units are not readily available and are not treated in this unit.)

XII. Evaporative cooling with rock-bed storage (Transparency 3)

(NOTE: Strictly speaking, evaporative cooling is not a solar system, but rock-bed storage of an air-heating solar system for storing cool air in the summer can be accomplished with the following procedure.)

A. Night air is evaporatively cooled and circulated through the rock-bed to cool down the pebbles in the storage unit

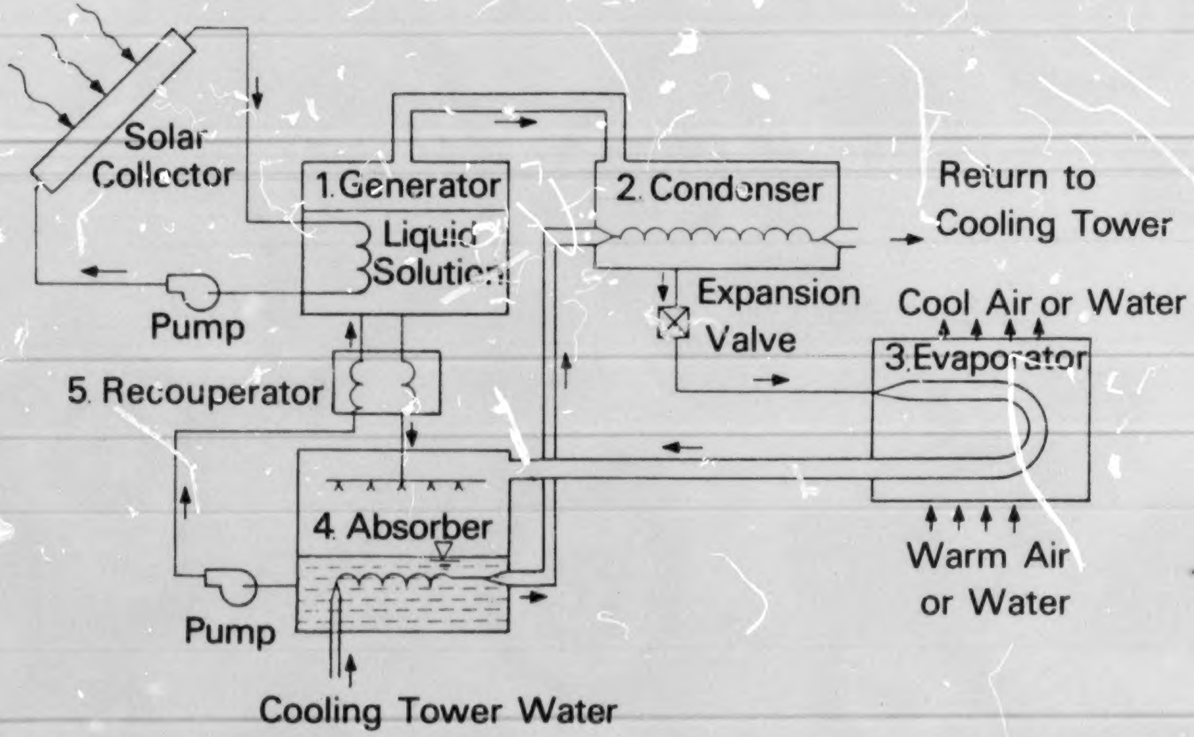
B. During the day, warm air from the building can be cooled by passing the air through the cool pebble bed

C. When a solar heating system with rock-bed storage is considered for cooling, it is advantageous to install the maximum storage volume consistent with heating system design

D. Evaporative cooling with rock-bed storage is best restricted to arid and semi-arid regions with cool nights and low wet-bulb temperatures

(NOTE: In marginal conditions, evaporative cooling through rock-bed storage might function, but it would produce an extremely uncomfortable humidity of more than 70 percent.)

Absorption Air Conditioner


Solar Collector
1. Generator
Liquid Solution
Pump
2. Condenser
Return to Cooling Tower
Expansion Valve
Cool Air or Water
3. Evaporator
5. Recouperator
4. Absorber
Pump
Warm Air or Water
Cooling Tower Water

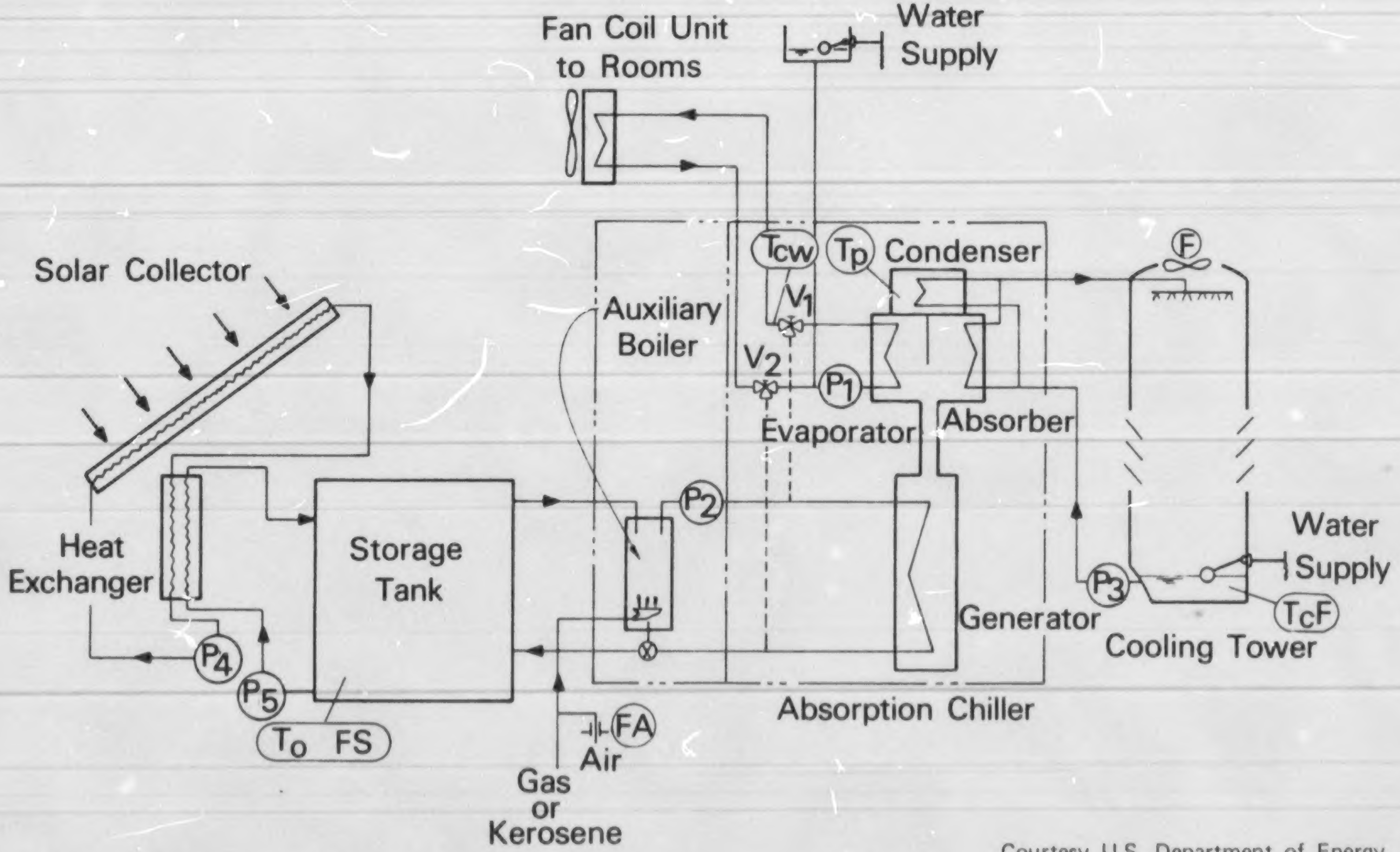
(NOTE: This type of unit is designed for commercial use only.)

Courtesy U.S. Department of Energy

TM 1

RS-125

Flow Schematic of a Water Chiller Operation



Fan Coil Unit to Rooms
Water Supply
Tcw
Tp
Condenser
F
Solar Collector
Auxiliary Boiler
V1
V2
P1
Evaporator
Absorber
P2
Heat Exchanger
Storage Tank
Water Supply
P3
TcF
Generator
Cooling Tower
P4
P5
To FS
FA
Air
Absorption Chiller
Gas or Kerosene

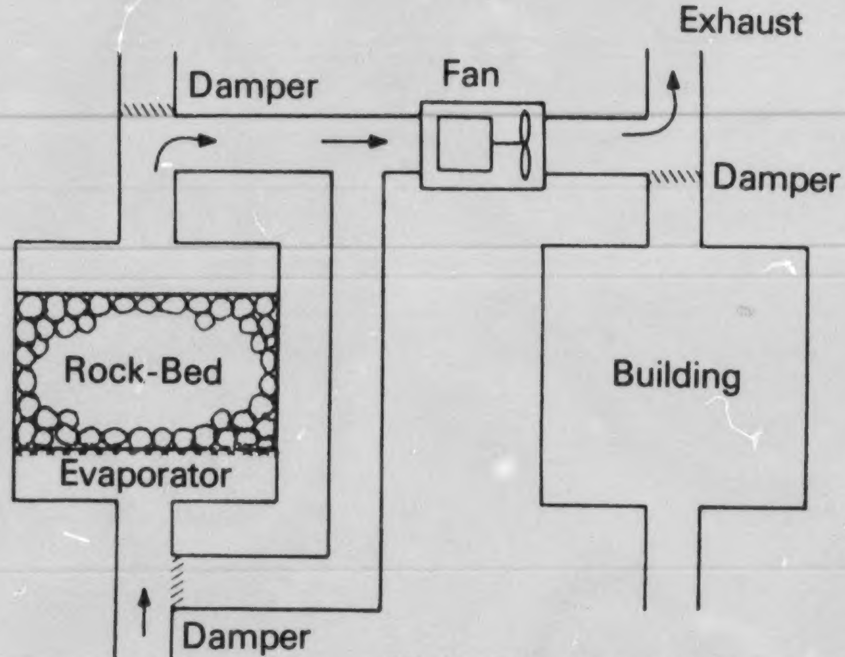
Courtesy U.S. Department of Energy

TM 2

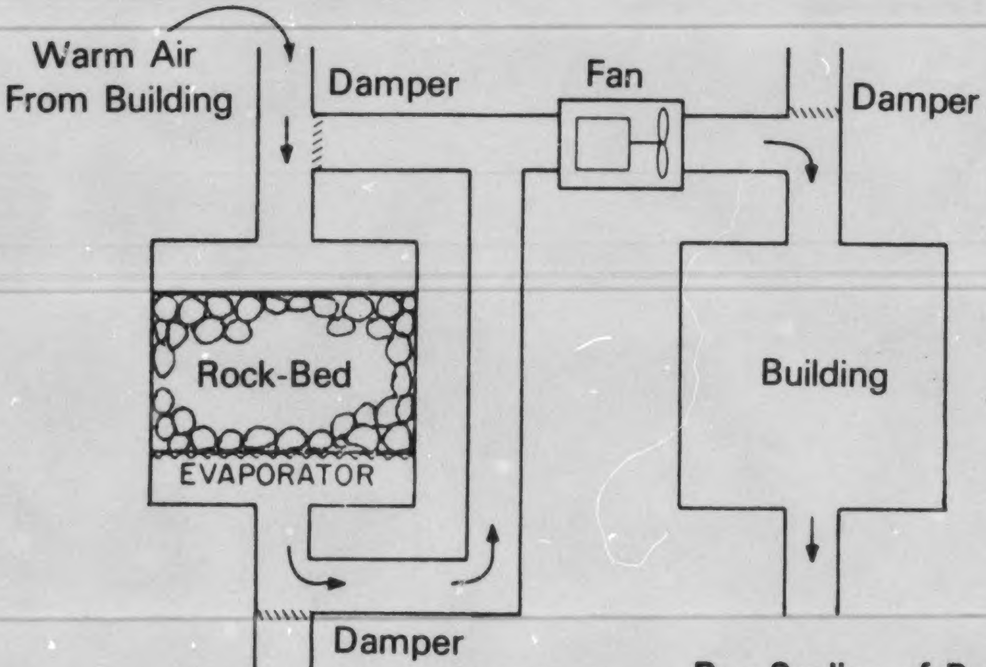
RS-127

(NOTE: This operation is for commercial use only.)

Evaporative Cooling with Rock-Bed Storage


Exhaust
Damper
Fan
Damper
Rock-Bed
Evaporator
Building
Damper
Night Air Inlet

Night Charging of Rock-Bed


Warm Air
From Building
Damper
Fan
Damper
Rock-Bed
EVAPORATOR
Building
Damper

Day Cooling of Building

Courtesy U.S. Department of Energy

LOAD CALCULATIONS AND SOLAR COOLING
UNIT III

ASSIGNMENT SHEET #1--COMPLETE A SUN-CHART WORKSHEET FOR A SPECIFIC SOLAR APPLICATION

Directions: Proceed carefully through the following example of how the CDA sun-chart worksheet should be filled out column by column; these examples are from a CDA sun-chart worksheet prepared for a solar application in Nashville, Tennessee, but all materials presented can be adapted to fit latitude, type of collector, and other pertinent factors necessary to produce an accurate "Results" column. Refer to the completed CDA sun-chart worksheet as you move through the example. The reference will assist you in understanding each step and its particular significance in the process.

DATA INPUT (Columns A through E)

Column A: Enter the collector heat gain factor from the chart in Figure 1; this chart is a general guideline, but heat gain factors are supplied by manufacturers of collectors; note that in the completed worksheet, the collector has 2 plates and a copper absorber with selective surface

FIGURE 1

COLLECTOR DESCRIPTION	A Heat Gain Factor	B Heat Loss Factor
1 Cover Plate Copper Absorber with Flat Black Surface	.78	1.35
2 Cover Plates Copper Absorber with Flat Black Surface	.72	.90
1 Cover Plate Copper Absorber Selective Surface	.76	.85
2 Cover Plates Copper Absorber Selective Surface	.70	.65

Courtesy Copper Development Association Inc.

Column B: Enter the collector heat loss factor from the chart in Figure 1; note what is entered on the completed worksheet and remember this information for collectors not listed on the chart in Figure 1 is available from the collector manufacturer

Column C: Enter the daytime average air temperature for the locale; this may be obtained from available charts or from a local or regional weather station; in the case of the completed worksheet, the daytime average temperature for Nashville, Tennessee during the month of January is 46°F and for the month of July is 87°F

ASSIGNMENT SHEET #1

Column D: Enter the amount of horizontal solar energy received by a horizontal surface on an average day in each month; this information is available in insolation tables which are included as examples in this activity; enter the number preceding the slash in the insolation chart; note that in the completed worksheet, the January figure is 601 and the July figure is 2033; the entry after the slash is a diffuse percent used interpolating information needed in Column E

Column E: Enter the collector tilt factor; from the completed worksheet, you can see the entry of 1.44 is the January tilt factor for the Nashville latitude of 36°. This requires interpolation, but here's how it works: In January, Nashville has a % diffuse factor of 65%. If a collector tilt of 51° (latitude plus 15°) is desired, we must interpolate between both the positions of latitude and the tables for % diffuse. First, interpolate for latitude on each of the two applicable % diffuse charts (60% and 80%). On the 60% chart, we interpolate between the January factor for a collector tilt of latitude +15°, for 32° latitude (1.37) and for 40° latitude (1.60). Since the latitude of the site (36°) is halfway between them, the result is 1.485, or call it 1.49. Similarly, for the 80% chart, the result is 1.28. Since the % diffuse for Nashville in January is 65%, an interpolation between 1.49 and 1.28 yields a tilt factor of 1.4375, call it 1.44, and that is the tilt factor that should be entered across from January in column E

COMPUTATION SECTION (Columns F through L)

Column F: This entry is obtained by multiplying the quantities from columns D and E; on the completed worksheet, the January figure would be 865.44, call it 865

ASSIGNMENT SHEET #1

Column G: Enter here the assumed collector input temperature as obtained from the following chart in Figure 2; for Nashville for an application that combines space heating and DHW, that figure is 100°; be careful with this part of the procedure because this chart was prepared specifically for Nashville; other locales will probably have different collector input temperatures from month to month

FIGURE 2

	Combined Space Heating and Domestic Water Heating	Domestic Water Heating Only (Add to Cold Water Supply Temperature)
January	100°	CWS + 20°
February	115°	CWS + 35°
March	140°	CWS + 60°
April	155°	CWS + 75°
May	165°	CWS + 85°
June	175°	CWS + 95°
July	180°	CWS +100°
August	180°	CWS +100°
September	175°	CWS + 95°
October	150°	CWS + 70°
November	130°	CWS + 50°
December	105°	CWS + 30°

Courtesy Copper Development Association Inc.

Column H: Enter here the temperature difference between the collector inlet and the daytime average air temperature; in other words, subtract Column C from Column G; in the case of the completed worksheet, the figure is 54

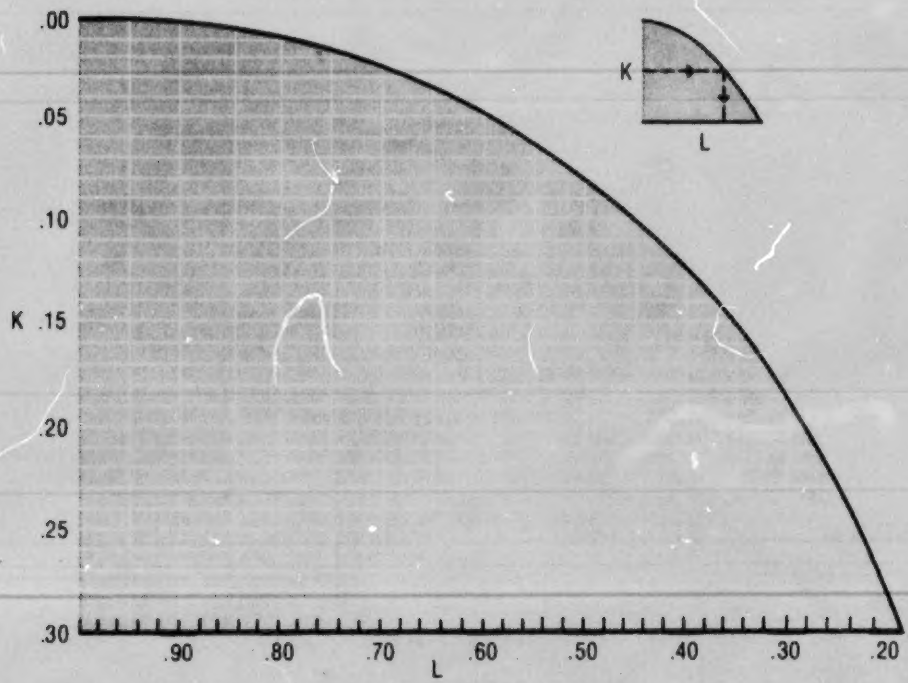
Column J: This entry is obtained by dividing Column B by column A and multiplying the result by 2 times the quantity from column H; in the completed worksheet, the figure is 100

Column K: This entry is obtained by dividing the result from Column J by the quantity from Column F; in the completed worksheet, the figure is .12; the figure in the completed worksheet is a little over 100, but call it 100

ASSIGNMENT SHEET #1

Column L: This entry is obtained by referring to the Collectable Energy Graph in Figure 3, finding the quantity obtained in Column K, then following the K axis across the graph until it intersects the curved L axis; the completed worksheet shows .42

FIGURE 3



Courtesy Copper Development Association Inc.

Result Column: This entry is obtained by multiplying the values from Columns F and L; this is the amount of heat collected in Btu per square foot per day, an average day in a particular month; on the completed worksheet, the figure for January is 363.30, but call it 363; once the rate of output from the collector has been determined, the designer can proceed to find the collector area needed for a specific application

Assignment: Using the blank CDA sun-chart worksheet provided with this activity, complete the worksheet with information provided by your instructor; this information should include specific latitude, average daytime temperature, heat gain factor and heat loss factor for a given collector, necessary collector inlet temperatures, and whatever materials are necessary to complete the assignment; you may refer as needed to the sample exercise which you have just completed; when you have finished the worksheet, and just for fun, write a brief note explaining why the columns in the worksheet jump from "H" to "J" and omit the "I." Good luck.

ASSIGNMENT SHEET #1

COMPLETED CDA SUN-CHART WORKSHEET

JOB: CDA Solar Home
LOCATION: Nashville, Tennessee
LATITUDE: 36° North

COLLECTOR TYPE: Double Glazed Selective Surface
COLLECTOR TILT: 51° (Latitude + 15°)
APPLICATION: Space and Water Heating

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG'S LIT	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG'S LIT	AVERAGE DAYTIME AIR TEMPERATURE °F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F = D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) °F	H = COLUMN G − COLUMN C °F	J = $\frac{B}{A}$ x 2H	K = $\frac{J}{F}$	L IS FOUND FROM FIGURE 41 USING K	TOTAL ENERGY COLLECTED = F x L BTU/SQ FT/DAY
JANUARY	.70	.65	46	601	1.44	865	100	54	100	.12	.42	363
FEBRUARY	.70	.65	48	882	1.30	1147	115	67	124	.11	.44	505
MARCH	.70	.65	57	1188	1.09	1295	140	83	154	.12	.42	544
APRIL	.70	.65	67	1638	.88	1441	155	88	163	.11	.44	634
MAY	.70	.65	76	1911	.63	1204	165	89	165	.14	.37	445
JUNE	.70	.65	84	2081	.61	1269	175	91	169	.13	.39	495
JULY	.70	.65	87	2033	.62	1260	180	93	173	.14	.37	466
AUGUST	.70	.65	86	1845	.89	1642	180	94	175	.11	.44	722
SEPTEMBER	.70	.65	81	1561	1.10	1717	175	94	175	.10	.46	790
OCTOBER	.70	.65	69	1199	1.42	1703	150	81	150	.09	.48	817
NOVEMBER	.70	.65	55	808	1.57	1269	130	75	139	.11	.44	558
DECEMBER	.70	.65	47	605	1.63	986	105	58	108	.11	.44	434

Courtesy Copper Development Association Inc.

ASSIGNMENT SHEET #1

AVERAGE MONTHLY AND YEARLY DEGREE DAYS FOR CITIES IN THE UNITED STATES AND CANADA a.b.c.(BASE 65)

HOW DEGREE DAYS ARE MEASURED

A degree day is a standard measure used by heating engineers to measure the heating season s coldness. The number of degree days in a calendar day is determined by subtracting the day s mean temperature from 65. If the high on a given day was 60 and the low was 40 the mean temperature that day would be 50. Subtracted from 65, this would give 15 degree days for that calendar day.

UNITED STATES

State	Station	Avg Winter Temp. F	July	Aug.	Sept.	Oct.	Nov	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Ala.	Birmingham A	54.2	0	0	6	93	363	555	592	462	363	108	9	0	2551
	Huntsville A	51.3	0	0	12	127	426	663	694	557	434	138	19	0	3070
	Mobile A	59.9	0	0	0	22	213	357	415	300	211	42	0	0	1560
	Montgomery A	55.4	0	0	0	68	330	527	543	417	316	90	0	0	2291
Alaska	Anchorage A	23.0	245	291	516	930	1284	1572	1631	1316	1293	879	592	315	10864
	Fairbanks A	6.7	171	332	642	1203	1833	2254	2359	1901	1739	1068	555	222	14279
	Juneau A	32.1	301	338	483	725	921	1135	1237	1070	1073	810	601	381	9075
	Nome A	13.1	481	496	693	1094	1455	1820	1875	1666	1770	1314	930	573	14171
Ariz.	Flagstaff A	35.6	46	68	201	558	867	1073	1169	991	911	651	437	180	7152
	Phoenix A	58.5	0	0	0	22	234	415	474	328	217	75	0	0	1765
	Tucson A	58.1	0	0	0	25	231	406	471	314	242	75	6	0	1800
	Winslow A	43.0	0	0	6	245	711	1008	1054	770	601	291	96	0	4782
	Yuma A	64.2	0	0	0	0	108	264	307	190	90	15	0	0	974
Ark.	Fort Smith A	50.3	0	0	12	127	450	704	781	596	456	144	22	0	3292
	Little Rock A	50.5	0	0	9	127	465	716	756	577	434	126	9	0	3219
	Texarkana A	54.2	0	0	0	78	345	561	626	468	350	105	0	0	2533
Calif.	Bakersfield A	55.4	0	0	0	37	282	502	546	364	267	105	19	0	2122
	Bishop A	46.0	0	0	48	260	576	797	874	680	555	306	143	36	4275
	Blue Canyon A	42.2	28	37	108	347	594	781	896	795	806	597	412	195	5596
	Burbank A	58.6	0	0	6	43	177	301	366	277	239	138	81	18	1646
	Eureka C	49.9	270	257	258	329	414	499	546	470	505	438	372	285	4643
	Fresno A	53.3	0	0	0	84	354	577	605	426	335	162	62	6	2611
	Long Beach A	57.8	0	0	9	47	171	316	397	311	264	171	93	24	1803
	Los Angeles A	57.4	28	28	42	78	180	291	372	302	288	219	158	81	2061
	Los Angeles C	60.3	0	0	6	31	132	229	310	230	202	123	68	18	1349
	Mt. Shasta C	41.2	25	34	123	406	696	902	983	784	738	525	347	159	5722
	Oakland A	53.5	53	50	45	127	309	481	527	400	353	255	180	90	2870
	Red Bluff A	53.8	0	0	0	53	318	555	605	428	341	168	47	0	2515
	Sacramento A	53.9	0	0	0	56	321	546	583	414	332	178	72	0	2502
	Sacramento C	54.4	0	0	0	62	312	533	561	392	310	173	76	0	2419
	Sandberg C	46.8	0	0	30	202	480	691	778	661	620	426	264	57	4209
	San Diego A	59.5	9	0	21	43	135	236	298	235	214	135	90	42	1458
	San Francisco A	53.4	81	78	60	143	306	462	508	395	363	279	214	126	3015
	San Francisco C	55.1	192	174	102	118	231	388	443	336	319	279	239	180	3001
	Santa Maria A	54.3	99	93	96	146	270	391	459	370	363	282	233	165	2967
Colo.	Alamosa A	29.7	65	99	279	639	1065	1420	1476	1162	1020	696	440	168	8529
	Colorado Springs A	37.3	9	25	132	456	825	1032	1128	938	893	582	319	84	6423
	Denver A	37.6	6	9	117	428	819	1035	1132	938	887	558	288	66	6283
	Denver C	40.8	0	0	90	366	714	905	1004	851	800	492	254	48	5524
	Grand Junction A	39.3	0	0	30	313	786	1113	1209	907	729	387	146	21	5641
	Pueblo A	40.4	0	0	54	326	750	986	1085	871	772	429	174	15	5462
Conn.	Bridgeport A	39.9	0	0	66	307	615	986	1079	966	853	510	208	27	5617
	Hartford A	37.3	0	12	117	394	714	1101	1190	1042	908	519	205	33	6235
	New Haven A	39.0	0	12	87	347	648	1011	1097	991	871	543	245	45	5897
Del.	Wilmington A	42.5	0	0	51	270	588	927	980	874	735	387	112	6	4930
D.C.	Washington A	45.7	0	0	33	217	519	834	871	762	626	288	74	0	4224
Fla.	Apalachicola C	61.2	0	0	0	16	153	319	347	260	180	33	0	0	1308
	Daytona Beach A	64.5	0	0	0	0	75	[illegible]	248	100	140	15	0	0	879
	Fort Myers A	68.6	0	0	0	0	24	109	146	101	62	0	0	0	442
	Jacksonville A	61.9	0	0	0	12	144	310	332	246	174	21	0	0	1239
	Key West A	73.1	0	0	0	0	0	28	40	31	9	0	0	0	108
	Lakeland C	66.7	0	0	0	0	57	164	195	146	99	0	0	0	661
	Miami A	71.1	0	0	0	0	0	65	74	56	19	0	0	0	214
	Miami Beach C	72.5	0	0	0	0	0	40	56	36	9	0	0	0	141
	Orlando A	65.7	0	0	0	0	72	198	220	165	105	6	0	0	766
	Pensacola A	60.4	0	0	0	19	195	353	400	277	183	36	0	0	1463
	Tallahassee A	60.1	0	0	0	28	198	360	375	286	202	36	0	0	1485
	Tampa A	66.4	0	0	0	0	60	171	202	148	102	0	0	0	683
	West Palm Beach A	68.4	0	0	0	0	6	65	87	64	31	0	0	0	253

Reprinted from *ASHRAE 1973* Systems Handbook, Chapter 43, "Energy Estimating Method"

a Data for United States cities from a publication of the United States Weather Bureau, *Monthly Normals of Temperature, Precipitation and Heating Degree Days* 1962, are for the period 1931 to 1960 inclusive. These data also include information from the 1963 Revisions to this publication, where available.

b Data for airport stations, A, and city stations, C, are both given where available.

c Data for Canadian cities where computed by the Climatology Division, Department of Transport from normal monthly mean temperatures, and the monthly values of heating degree days data were obtained using the National Research Council computer and a method devised by H.C.S. Thorn of the United States Weather Bureau. The heating degree days are based on the period from 1931 to 1960.

ASSIGNMENT SHEET #1

AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

State	Station	Avg. Winter Temp °F	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Ga.	Athens A	51.8	0	0	12	115	405	632	642	529	431	141	22	0	2929
	Atlanta A	51.7	0	0	18	124	417	648	636	518	428	147	25	0	2961
	Augusta A	54.5	0	0	0	78	333	552	549	[illegible]	350	90	0	0	2397
	Columbus A	54.8	0	0	0	87	333	543	552	[illegible]	338	96	0	0	2383
	Macon A	56.2	0	0	0	71	297	502	505	[illegible]	295	63	0	0	2136
	Rome A	49.9	0	0	24	161	474	701	710	577	468	177	34	0	3326
	Savannah A	57.8	0	0	0	47	246	437	437	353	254	45	0	0	1819
	Thomasville C	60.0	0	0	0	25	198	366	394	305	208	33	0	0	1529
Hawaii	Lihue A	72.7	0	0	0	0	0	0	0	0	0	0	0	0	0
	Honolulu A	74.2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hilo A	71.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Idaho	Boise A	39.7	0	0	132	415	792	1017	1113	854	722	438	245	81	5809
	Lewiston A	41.0	0	0	123	403	756	933	1063	815	694	426	239	90	5542
	Pocatello A	34.8	0	0	172	493	900	1166	1324	1058	905	555	319	141	7033
Ill.	Cairo C	47.9	0	0	36	164	513	791	856	680	539	195	47	0	3821
	Chicago (O'Hare) A	35.8	0	12	117	381	807	1166	1265	1086	939	534	260	72	6639
	Chicago (Midway) A	37.5	0	0	81	326	753	1113	1209	1044	890	480	211	48	6155
	Chicago C	38.9	0	0	66	279	705	1051	1150	1000	868	489	226	48	5882
	Moline A	36.4	0	9	99	335	774	1181	1314	1100	918	450	189	39	6408
	Peoria A	38.1	0	6	87	326	759	1113	1218	1025	849	426	183	33	6025
	Rockford A	34.8	6	9	114	400	837	1221	1333	1137	961	516	236	60	6830
	Springfield A	40.6	0	0	72	291	696	1023	1135	935	769	354	136	18	5429
Ind.	Evansville A	45.0	0	0	66	220	606	896	955	767	620	237	68	0	4435
	Fort Wayne A	37.3	0	9	105	378	783	1135	1178	1028	890	471	189	39	6205
	Indianapolis A	39.6	0	0	90	316	723	1051	1113	949	809	432	177	39	5699
	South Bend A	36.6	0	6	111	372	777	1125	1221	1070	933	525	239	60	6439
Iowa	Burlington A	37.6	0	0	93	322	768	1135	1259	1042	859	426	177	33	6114
	Des Moines A	35.5	0	6	96	363	828	1225	1370	1137	915	438	180	30	6588
	Dubuque A	32.7	12	31	156	450	906	1287	1420	1204	1026	546	260	78	7376
	Sioux City A	34.0	0	9	108	369	867	1240	1435	1198	989	483	214	39	6951
	Waterloo A	32.6	12	19	138	428	909	1296	1460	1221	1023	531	229	54	7320
Kans.	Concordia A	40.4	0	0	57	276	705	1023	1163	935	781	372	149	18	5479
	Dodge City A	42.5	0	0	33	251	666	939	1051	840	719	354	124	9	4986
	Goodland A	37.8	0	6	81	381	810	1073	1166	955	884	507	236	42	6141
	Topeka A	41.7	0	0	57	270	672	980	1122	893	722	330	124	12	5182
	Wichita A	44.2	0	0	33	229	618	905	1023	804	645	270	87	6	4620
Ky.	Covington A	41.4	0	0	75	291	669	983	1035	893	756	390	149	24	5265
	Lexington A	43.8	0	0	54	239	609	902	946	818	685	325	105	0	4683
	Louisville A	44.0	0	0	54	248	609	890	930	818	682	315	105	9	4660
La.	Alexandria A	57.5	0	0	0	56	273	431	471	361	260	69	0	0	1921
	Baton Rouge A	59.8	0	0	0	31	216	369	409	294	208	33	0	0	1560
	Lake Charles A	60.5	0	0	0	19	210	341	381	274	195	39	0	0	1459
	New Orleans A	61.0	0	0	0	19	192	322	363	258	192	39	0	0	1385
	New Orleans C	61.8	0	0	0	12	165	291	344	241	177	24	0	0	1254
	Shreveport A	56.2	0	0	0	47	297	477	552	426	304	81	0	0	2184
Me.	Caribou A	24.4	78	115	336	682	1044	1535	1690	1470	1308	858	468	183	9767
	Portland A	33.0	12	53	195	508	807	1215	1339	1182	1042	675	372	111	7511
Md.	Baltimore A	43.7	0	0	48	264	585	905	936	820	679	327	90	0	4654
	Baltimore C	46.2	0	0	27	189	486	806	859	762	629	288	65	0	4111
	Frederich A	42.0	0	0	66	307	624	955	995	876	741	384	127	12	5087
Mass.	Boston A	40.0	0	9	60	316	603	983	1088	972	846	513	208	36	5634
	Nantucket A	40.2	12	22	93	332	573	896	992	941	896	621	384	129	5891
	Pittsfield A	32.6	25	59	219	524	831	1231	1339	1196	1063	660	326	105	7578
	Worcester A	34.7	6	34	147	450	774	1172	1271	1123	998	612	304	78	6969
Mich.	Alpena A	29.7	68	105	273	580	912	1268	1404	1299	1218	777	446	156	8506
	Detroit (City) A	37.2	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232
	Detroit (Wayne) A	37.1	0	0	96	353	738	1088	1194	1061	933	534	239	57	6293
	Detroit (Willow Run) A	37.2	0	0	90	357	750	1104	1190	1053	921	519	229	45	6258
	Escanaba C	29.6	59	87	243	539	924	1293	1445	1296	1203	777	456	159	8481
	Flint A	33.1	16	40	159	465	843	1212	1330	1198	1066	639	319	90	7377
	Grand Rapids A	34.9	9	28	135	434	804	1147	1259	1134	1011	579	279	75	6894
	Lansing A	34.8	6	22	138	431	813	1163	1262	1142	1011	579	273	69	6909
	Marquette C	30.2	59	81	240	527	936	1268	1411	1268	1187	771	468	177	8393
	Muskegon A	36.0	12	28	120	400	762	1088	1209	1100	995	594	310	78	6696
	Sault Ste. Marie A	27.7	96	105	279	580	951	1367	1525	1380	1277	810	477	201	9048
Minn.	Duluth A	23.4	71	109	330	632	1131	1581	1745	1518	1355	840	490	198	10000
	Minneapolis A	28.3	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382
	Rochester A	28.8	25	34	186	474	1005	1438	1593	1366	1150	630	301	93	8295
Miss.	Jackson A	55.7	0	0	0	65	315	502	546	414	310	87	0	0	2239
	Meridian A	55.4	0	0	0	81	339	518	543	417	310	81	0	0	2289
	Vicksburg C	56.9	0	0	0	53	279	462	512	384	282	69	0	0	2041
Mo.	Columbia A	42.3	0	0	54	251	651	967	1076	874	716	324	121	12	5046
	Kansas City A	43.9	0	0	39	220	612	905	1032	818	682	294	109	0	4711
	St. Joseph A	40.3	0	6	60	285	708	1039	1172	949	769	348	133	15	5484
	St. Louis A	43.1	0	0	60	251	627	936	1026	848	704	312	121	15	4900

ASSIGNMENT SHEET #1

AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

State	Station			July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Yearly Total
—	St. Louis	C	44.8	0	0	36	202	576	884	977	801	651	270	87	0	4484
	Springfield	A	44.5	0	0	45	223	600	877	973	781	660	291	105	6	4900
Mont.	Billings	A	34.5	6	15	186	487	897	1135	1296	1100	970	570	285	102	7049
	Glasgow	A	26.4	31	47	270	608	1104	1466	1711	1439	1187	648	335	150	8996
	Great Falls	A	32.8	28	53	258	543	921	1169	1349	1154	1063	642	384	186	7750
	Havre	A	28.1	28	53	306	595	1065	1367	1584	1364	1181	657	338	162	8700
	Havre	C	29.8	19	37	252	539	1014	1321	1528	1305	1116	612	304	135	8182
	Helena	A	31.1	31	59	294	601	1002	1265	1438	1170	1042	651	381	195	8129
	Kalispell	A	31.4	50	99	321	654	1020	1240	1401	1134	1029	639	397	207	8191
	Miles City	A	31.2	6	6	174	502	972	1296	1504	1252	1057	579	276	99	7723
	Missoula	A	31.5	34	74	303	651	1035	1287	1420	1120	970	621	391	219	8125
Neb.	Grand Island	A	36.0	0	6	108	381	834	1172	1314	1089	908	462	211	45	6530
	Lincoln	C	38.8	0	6	75	301	726	1066	1237	1016	834	402	171	30	5864
	Norfolk	A	34.0	9	0	111	397	873	1234	1414	1179	983	498	233	48	6979
	North Platte	A	35.5	0	6	123	440	885	1166	1271	1039	930	519	248	57	6684
	Omaha	A	35.6	0	12	105	357	828	1175	1355	1126	939	465	208	42	6612
	Scottsbluff	A	35.9	0	0	138	459	876	1128	1231	1008	921	552	285	75	6673
	Valentine	A	32.6	9	12	165	493	942	1237	1395	1176	1045	579	288	84	7425
Nev.	Elko	A	34.0	9	34	225	561	924	1197	1314	1036	911	621	409	192	7433
	Ely	A	33.1	28	43	234	592	939	1184	1308	1075	977	672	456	225	7733
	Las Vegas	A	53.5	0	0	0	78	387	617	688	487	335	111	6	0	2709
	Reno	A	39.3	43	87	204	490	801	1026	1073	823	729	510	357	189	6332
	Winnemucca	A	36.7	0	34	210	536	876	1091	1172	916	837	573	363	153	6761
N.H.	Concord	A	33.0	6	50	177	505	822	1240	1358	1184	1032	636	298	75	7383
	Mt. Washington Obsv.	-	15.2	493	536	720	1057	1341	1742	1820	1663	1652	1260	930	603	13817
N.J.	Atlantic City	A	43.2	0	0	39	251	549	880	936	848	741	420	133	15	4812
	Newark	A	42.8	0	0	30	248	573	921	983	876	729	381	118	0	4589
	Trenton	C	42.4	0	0	57	264	576	924	989	885	753	399	121	12	4980
N.M.	Albuquerque	A	45.0	0	0	12	229	642	868	930	703	595	288	81	0	4348
	Clayton	A	42.0	0	6	66	310	699	899	986	812	747	429	183	21	5158
	Raton	A	38.1	9	28	126	431	825	1048	1116	904	834	543	301	63	6228
	Roswell	A	47.5	0	0	18	202	573	806	840	641	481	201	31	0	3793
	Silver City	A	48.0	0	0	6	183	525	729	791	605	518	261	87	0	3705
N.Y.	Albany	A	34.6	0	19	138	440	777	1194	1311	1156	992	564	239	45	6875
	Albany	C	37.2	0	9	102	375	699	1104	1218	1072	908	498	186	30	6201
	Binghamton	A	33.9	22	65	201	471	810	1184	1277	1154	1045	645	313	99	7286
	Binghamton	C	36.6	0	28	141	406	732	1107	1190	1081	949	543	229	45	6451
	Buffalo	A	34.5	19	37	141	440	777	1156	1256	1145	1039	645	329	78	7062
	New York (Cent. Park)		42.8	0	0	30	233	540	902	986	885	760	408	118	9	4871
	New York (La Guardia)	A	43.1	0	0	27	223	528	887	973	879	750	414	124	6	4811
	New York (Kennedy)	A	41.4	0	0	36	248	564	933	1029	935	815	480	167	12	5219
	Rochester	A	35.4	9	31	126	415	747	1125	1234	1123	1014	597	279	48	6748
	Schenectady	C	35.4	0	22	123	422	756	1159	1283	1131	970	543	211	30	6650
	Syracuse	A	35.2	6	28	132	415	744	1153	1271	1140	1004	570	248	45	6756
N.C.	Asheville	C	46.7	0	0	48	245	555	775	784	683	592	273	87	0	4042
	Cape Hatteras		53.3	0	0	0	78	273	521	580	518	440	177	25	0	2612
	Charlotte	A	50.4	0	0	6	124	438	691	691	582	481	156	22	0	3191
	Greensboro	A	47.5	0	0	33	192	513	778	784	672	552	234	47	0	3805
	Raleigh	A	49.4	0	0	21	164	450	716	725	616	487	180	34	0	3393
	Wilmington	A	54.6	0	0	0	74	291	521	546	462	357	96	0	0	2347
	Winston-Salem	A	48.4	0	0	21	171	483	747	753	652	524	207	37	0	3595
N.D.	Bismarck	A	26.6	34	28	222	577	1083	1463	1708	1442	1203	645	329	117	8851
	Devils Lake	C	22.4	40	53	273	642	1191	1634	1872	1579	1345	753	381	138	9901
	Fargo	A	24.8	28	37	219	574	1107	1569	1789	1520	1262	690	332	99	9226
	Williston	A	25.2	31	43	261	601	1122	1513	1758	1473	1262	681	357	141	9243
Ohio	Akron-Canton	A	38.1	0	9	96	381	726	1070	1138	1016	871	489	202	39	6037
	Cincinnati	C	45.1	0	0	39	208	558	862	915	790	642	294	96	6	4410
	Cleveland	A	37.2	9	25	105	384	738	1088	1159	1047	918	552	260	66	6351
	Columbus	A	39.7	0	6	84	347	714	1039	1088	949	809	426	171	27	5660
	Columbus	C	41.5	0	0	57	285	651	977	1032	902	760	396	136	15	5211
	Dayton	A	39.8	0	6	78	310	696	1045	1097	955	809	429	167	30	5622
	Mansfield	A	36.9	9	22	114	397	768	1110	1169	1042	924	543	245	60	6403
	Sandusky	C	39.1	0	6	66	313	684	1032	1107	991	868	495	198	36	5796
	Toledo	A	36.4	0	16	117	406	792	1138	1200	1056	924	543	242	60	6494
	Youngstown	A	36.8	6	19	120	412	771	1104	1169	1047	921	540	248	60	6417
Okla.	Oklahoma City	A	48.3	0	0	15	164	498	766	868	664	527	189	34	0	3725
	Tulsa	A	47.7	0	0	18	158	522	787	893	683	539	213	47	0	3860
Ore.	Astoria	A	45.6	146	130	210	375	561	679	753	622	636	480	363	231	5186
	Burns	C	35.9	12	37	210	515	867	1113	1246	988	856	570	366	177	6957
	Eugene	A	45.6	34	34	129	366	585	719	803	627	589	426	279	135	4726
	Meacham	A	34.2	84	124	288	580	918	1091	1209	1005	983	726	527	339	7874
	Medford	A	43.2	0	0	78	372	678	871	918	697	642	432	242	78	5008
	Pendleton	A	42.6	0	0	111	350	711	884	1017	773	617	396	205	63	5127
	Portland	A	45.6	25	28	114	335	597	735	825	644	586	396	245	105	4635
	Portland	C	47.4	12	16	75	267	534	679	769	594	536	351	198	78	4109

ASSIGNMENT SHEET #1

AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

State	Station		Avg Winter Temp. F	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Yearly Total
	Roseburg	A	46.3	22	16	105	329	567	713	766	608	570	405	267	123	4491
	Salem	A	45.4	37	31	111	338	594	729	822	647	611	417	273	144	4754
Pa	Allentown	A	38.9	0	0	90	353	693	1045	1116	1002	849	471	167	24	5810
	Erie	A	36.8	0	25	102	391	714	1063	1169	1081	973	585	288	60	6451
	Harrisburg	A	41.2	0	0	63	298	648	992	1045	907	766	396	124	12	5251
	Philadelphia	A	41.8	0	0	60	297	620	965	1016	889	747	392	118	40	5144
	Philadelphia	C	44.5	0	0	30	205	513	856	924	823	691	351	93	0	4486
	Pittsburgh	A	38.4	0	9	105	375	726	1063	1119	1002	874	480	195	39	5987
	Pittsburgh	C	42.2	0	0	60	291	615	930	983	885	763	390	124	12	5053
	Reading	C	42.4	0	0	54	257	597	939	1001	885	735	372	105	0	[illegible]
	Scranton	A	37.2	0	19	132	434	762	1104	1156	1028	893	498	195	33	6254
	Williamsport	A	38.5	0	9	111	375	717	1073	1122	1002	856	468	177	24	5934
R.I.	Block Island	A	40.1	0	16	78	307	594	902	1020	955	877	612	344	99	5804
	Providence	A	38.8	0	16	96	372	660	1023	1110	988	868	534	236	51	5954
S.C.	Charleston	A	56.4	0	0	0	59	282	471	487	389	291	54	0	0	2033
	Charleston	C	57.9	0	0	0	34	210	425	443	367	273	42	0	0	1794
	Columbia	A	54.0	0	0	0	84	345	577	570	470	357	81	0	0	2484
	Florence	A	54.5	0	0	0	78	315	552	552	459	347	84	0	0	2387
	Greenville-Spartenburg	A	51.6	0	0	6	121	399	651	660	546	446	132	19	0	2980
S.D.	Huron	A	28.8	9	12	165	508	1014	1432	1628	1355	1125	600	288	87	8223
	Rapid City	A	33.4	22	12	165	481	897	1172	1333	1145	1051	615	326	126	7345
	Sioux Falls	A	30.6	19	25	168	462	972	1361	1544	1285	1082	573	270	78	7839
Tenn	Bristol	A	46.2	0	0	51	236	573	828	828	700	598	261	68	0	4143
	Chattanooga	A	50.3	0	0	18	143	468	698	722	577	453	150	25	0	3254
	Knoxville	A	49.2	0	0	30	171	489	725	732	613	493	198	43	0	3494
	Memphis	A	50.5	0	0	18	130	447	698	729	585	456	147	22	0	3232
	Memphis	C	51.6	0	0	12	102	396	648	710	568	434	129	16	0	3015
	Nashville	A	48.9	0	0	30	158	495	732	778	644	512	189	40	0	3578
	Oak Ridge	C	47.7	0	0	39	192	531	772	778	669	552	228	56	0	3817
Tex	Abilene	A	53.9	0	0	0	99	366	585	642	470	347	114	0	0	2624
	Amarillo	A	47.0	0	0	18	205	570	797	877	664	546	252	56	0	3985
	Austin	A	59.1	0	0	0	31	225	388	468	325	223	51	0	0	1711
	Brownsville	A	67.7	0	0	0	0	66	149	205	106	74	0	0	0	600
	Corpus Christi	A	64.6	0	0	0	0	120	220	291	174	109	0	0	0	914
	Dallas	A	55.3	0	0	0	62	321	524	601	440	319	90	6	0	2363
	El Paso	A	52.9	0	0	0	84	414	648	685	445	319	105	0	0	2700
	Fort Worth	A	55.1	0	0	0	65	324	536	614	448	319	99	0	0	2405
	Galveston	A	62.2	0	0	0	6	147	276	360	263	189	33	0	0	1274
	Galveston	C	62.0	0	0	0	0	138	270	350	258	189	30	0	0	1235
	Houston	A	61.0	0	0	0	6	183	307	384	288	192	36	0	0	1396
	Houston	C	62.0	0	0	0	0	165	288	363	258	174	30	0	0	1278
	Laredo	A	66.0	0	0	0	0	105	217	267	134	74	0	0	0	797
	Lubbock	A	48.8	0	0	18	174	513	744	800	613	484	201	31	0	3578
	Midland	A	53.8	0	0	0	87	381	592	651	468	322	90	0	0	2591
	Port Arthur	A	60.5	0	0	0	22	207	329	384	274	192	39	0	0	1447
	San Angelo	A	56.0	0	0	0	68	318	536	567	412	288	66	0	0	2255
	San Antonio	A	60.1	0	0	0	31	204	363	428	286	195	39	0	0	1546
	Victoria	A	62.7	0	0	0	6	150	270	344	230	152	21	0	0	1173
	Waco	A	57.2	0	0	0	43	270	456	536	389	270	66	0	0	2030
	Wichita Falls	A	53.0	0	0	0	99	381	632	698	518	378	120	6	0	2832
Utah	Milford	A	36.5	0	0	99	443	867	1141	1252	988	822	519	279	87	6497
	Salt Lake City	A	38.4	0	0	81	419	849	1082	1172	910	763	459	233	84	6052
	Wendover	A	39.1	0	0	48	372	822	1091	1178	902	729	408	177	51	5778
Vt	Burlington	A	29.4	28	65	207	539	891	1349	1513	1333	1187	714	353	90	8269
Va	Cape Henry	C	50.0	0	0	0	112	360	645	694	633	536	246	53	0	3279
	Lynchburg	A	46.0	0	0	51	223	540	822	849	731	605	267	78	0	4166
	Norfolk	A	49.2	0	0	0	136	408	698	738	655	533	216	37	0	3421
	Richmond	A	47.3	0	0	36	214	495	784	815	703	546	219	53	0	3865
	Roanoke	A	46.1	0	0	51	229	549	825	834	722	614	261	65	0	4150
Wash	Olympia	A	44.2	68	71	198	422	636	753	834	675	645	450	307	177	5236
	Seattle-Tacoma	A	44.2	56	62	162	391	633	750	828	678	657	474	295	159	5145
	Seattle	C	46.9	50	47	129	329	543	657	738	539	577	396	242	117	4424
	Spokane	A	36.5	9	25	168	493	879	1082	1231	980	834	531	288	135	6655
	Walla Walla	C	43.8	0	0	87	310	681	843	986	745	589	342	177	45	4805
	Yakima	A	39.1	0	12	144	450	828	1039	1163	868	713	435	220	69	5941
W Va	Charleston	A	44.8	0	0	63	254	591	865	880	770	648	300	96	9	4476
	Elkins	A	40.1	9	25	135	400	729	992	1008	896	791	444	198	48	5675
	Huntington	A	45.0	0	0	63	257	585	856	880	764	636	294	99	12	4446
	Parkersburg	C	43.5	0	0	60	264	606	905	942	826	691	339	115	6	4754
Wisc	Green Bay	A	30.3	28	50	174	484	924	1333	1494	1313	1141	654	335	99	8029
	La Crosse	A	31.5	12	19	153	437	924	1339	1504	1277	1070	540	245	69	7589
	Madison	A	30.9	25	40	174	474	930	1330	1473	1274	1113	618	310	102	7863
	Milwaukee	A	32.6	43	47	174	471	876	1252	1376	1193	1054	642	372	135	7635
Wyo	Casper	A	33.4	6	16	192	524	942	1169	1290	1084	1020	657	381	129	7410
	Cheyenne	A	34.2	28	37	219	543	909	1085	1212	1042	1026	702	428	150	7381
	Lander	A	31.4	6	19	204	555	1020	1299	1417	1145	1017	654	381	153	7870
	Sheridan	A	32.5	25	31	219	539	948	1200	1355	1154	1051	642	366	150	7680

ASSIGNMENT SHEET #1

AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

CANADA

Prov	Station		Avg Winter Temp	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Yearly Total
Alta	Banff	C	NOT AVAILABLE	220	295	498	797	1185	1485	1624	1364	1237	855	589	402	10551
	Calgary	A		109	186	402	719	1110	1389	1575	1379	1268	798	477	291	9703
	Edmonton	A		74	180	411	738	1215	1603	1810	1520	1330	765	400	222	10268
	Lethbridge	A		56	112	318	611	1011	1277	1497	1291	1159	696	403	213	8644
B.C.	Kamloops	A		22	40	189	546	894	1138	1314	1057	818	462	217	102	6799
	Prince George*	A		236	251	444	747	1110	1420	1612	1319	1122	747	468	279	9755
	Prince Rupert	C		273	248	339	539	708	868	936	808	812	648	493	357	7029
	Vancouver*	A		81	87	219	456	657	787	862	723	676	501	310	156	5515
	Victoria*	A		136	140	225	462	663	775	840	718	691	504	341	204	5699
	Victoria	C		172	184	243	426	607	723	805	668	660	487	354	250	5579
Man.	Brandon*	A		47	90	357	747	1290	1792	2034	1737	1476	837	431	198	11036
	Churchill	A		360	375	681	1082	1620	2248	2558	2277	2130	1569	1153	675	16728
	The Pas	C		59	127	429	831	1440	1981	2232	1853	1624	969	508	228	12281
	Winnipeg	A		38	71	322	683	1251	1757	2008	1719	1465	813	405	147	10679
N.B.	Fredericton*	A		78	68	234	592	915	1392	1541	1379	1172	753	406	141	8671
	Moncton	C		62	105	276	611	891	1342	1482	1336	1194	789	468	171	8727
	St. John	C		109	102	246	527	807	1194	1370	1229	1097	756	490	249	8219
Nod	Argentia	A		260	167	294	564	750	1001	1159	1085	1091	879	707	483	8440
	Corner Brook	C		102	133	324	642	873	1194	1358	1283	1212	885	639	333	8978
	Gander	A		121	152	330	670	909	1231	1370	1266	1243	939	657	366	9254
	Goose*	A		130	205	444	843	1227	1745	1947	1689	1494	1074	741	348	11887
	St. John's*	A		186	180	342	651	831	1113	1262	1170	1187	927	710	432	8991
N.W.T.	Aklavik	C		273	459	807	1414	2064	2530	2632	2336	2282	1674	1083	483	18017
	Fort Norman	C		164	341	666	1234	1959	2474	2592	2209	2058	1386	732	294	16109
	Resolution Island	C		843	831	900	1113'	1311	1724	2021	1850	1817	1488	1181	942	16021
N.S.	Halifax	C		58	51	180	457	710	1074	1213	1122	1030	742	487	237	7361
	Sydney	A		62	71	219	518	765	1113	1262	1206	1150	840	567	276	8049
	Yarmouth	A		102	115	225	471	696	1029	1156	1065	1004	726	493	258	7340
Ont	Cochrane	C		96	180	405	760	1233	1776	1978	1701	1528	963	570	222	11412
	Fort William	A		90	133	366	694	1140	1597	1792	1557	1380	876	543	237	10405
	Kapuskasing	C		74	171	405	756	1245	1807	2037	1735	1562	978	580	222	11572
	Kitchener	C		16	59	177	505	855	1234	1342	1226	1101	663	322	66	7566
	London	A		12	43	159	477	837	1206	1305	1198	1066	648	332	66	7349
	North Bay	C		37	90	267	608	990	1507	1680	1463	1277	780	400	120	9219
	Ottawa	C		25	81	222	567	936	1469	1624	1441	1231	708	341	90	8735
	Toronto	C		7	18	151	439	760	1111	1233	1119	1013	616	298	62	6827
P.E.I.	Charlottetown	C		40	53	198	518	804	1215	1380	1274	1169	813	496	204	8164
	Summerside	C		47	84	216	546	840	1246	1438	1291	1206	841	518	216	8489
Que	Arvida	C		102	136	327	682	1074	1659	1879	1619	1407	891	521	231	10528
	Montreal*	A		9	43	165	521	862	1392	1566	1381	1175	684	316	69	8203
	Montreal	C		16	28	165	496	864	1355	1510	1328	1138	657	288	54	7899
	Quebec*	A		56	84	273	636	996	1516	1665	1477	1296	819	428	126	9372
	Quebec	C		40	68	243	592	972	1473	1612	1418	1228	780	400	111	8937
Sasks.	Prince Albert	A		81	136	414	797	1368	1872	2108	1763	1559	867	446	219	11630
	Regina	A		78	93	360	741	1284	1711	1965	1687	1473	804	409	201	10806
	Saskatoon	C		56	87	372	750	1302	1758	2006	1689	1463	798	403	186	10870
Y.T.	Dawson	C		164	326	645	1197	1875	2415	2561	2150	1838	1068	570	258	15067
	Mayo Landing	C		208	366	648	1135	1794	2325	2427	1992	1665	1020	590	294	14454

*The data for these normals were from the full ten-year period 1951-1960 adjusted to the standard normal period 1931-1960

ASSIGNMENT SHEET #1

INSOLATION AND PERCENT DIFFUSE TABLES
BTU per sq. ft. per day/% DIFFUSE

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
ALABAMA													
Birmingham	33.6°	706/53	967/48	1295/45	1672/40	1855/40	1917/40	1809/42	1722/40	1454/41	1210/39	858/45	661/51
Mobile	30.7°	828/48	1099/45	1406/41	1721/39	1871/39	1867/41	1714/46	1640/44	1449/44	1298/38	955/44	759/49
Montgomery	32.3°	751/51	1013/47	1339/44	1728/39	1896/39	1971/38	1839/41	1744/40	1467/42	1261/38	915/44	719/49
ALASKA													
Annette	55.0°	232/50	424/53	870/42	1342/41	1611/45	1615/49	1615/47	1257/50	961/47	450/58	217/62	151/59
Bethel	60.8°	136/41	413/33	1040/18	1640/22	1692/40	1655/48	1364/55	936/60	734/53	431/46	166/48	85/44
Fairbanks	64.8°	70/23	280/36	859/20	1419/28	1758/36	1943/39	1637/45	1338/41	678/51	317/48	100/38	22/32
Matanuska	61.6°	118/42	339/42	892/28	1312/37	1607/42	1703/46	1508/49	1158/50	730/53	369/51	140/51	55/55
ARIZONA													
Page	36.9°	1106/18	1408/19	1939/13	2278/16	2562/16	2606/19	2507/20	2197/23	1902/21	1482/21	1143/20	896/27
Phoenix	33.4°	1020/31	1374/27	1813/22	2353/15	2674/13	2738/14	2485/21	2291/21	2014/20	1575/21	1150/27	932/32
Prescott	34.6°	1015/29	1334/27	1776/23	2274/18	2628/15	2761/14	2308/27	2090/28	1953/21	1542/21	1139/24	926/30
Tucson	32.1°	1098/29	1431/25	1863/22	2362/18	2670/13	2728/14	2340/25	2181/25	1978/22	1601/22	1207/25	995/31
Winslow	35.0°	984/30	1326/27	1779/22	2282/18	2593/16	2709/15	2345/25	2139/26	1927/21	1512/22	1118/25	894/31
Yuma	32.7°	1095/28	1442/24	1918/19	2411/14	2726/12	2812/12	2451/22	2327/20	2050/19	1622/20	1214/24	990/29
ARKANSAS													
Fort Smith	35.3°	743/47	999/45	1311/42	1615/41	1911/38	2088/34	2064/34	1876/34	1504/39	1200/38	851/42	682/47
Little Rock	34.7°	731/49	1002/45	1312/42	1610/42	1928/38	2105/34	2031/36	1860/36	1517/38	1228/37	847/44	673/49
CALIFORNIA													
Arcata	41.0°	528/53	793/48	1132/48	1586/40	1841/40	1960/39	1807/42	1578/44	1341/41	935/45	593/51	469/54
Bakersfield	35.4°	786/45	1101/36	1594/30	2093/24	2508/19	2748/14	2881/14	2419/16	1991/19	1457/24	941/37	677/47
Daggett	34.9°	957/32	1279/29	1772/23	2273/18	2590/16	2764/14	2602/18	2381/18	2007/19	1515/22	1084/28	875/33
Davis	38.5°	583/53	944/42	1482/31	1947/28	2345/23	2508/21	2544/19	2252/21	1836/22	1283/29	796/53	546/51
El Toro	33.7°	947/36	1235/33	1600/31	1928/31	2068/33	2193/31	2362/29	2154/25	1736/30	1356/32	1026/34	869/37
Fresno	36.8°	645/51	999/42	1524/31	1965/28	2308/26	2529/21	2524/20	2274/21	1871/22	1355/28	841/53	549/55
Inyokern	35.6°	1150/16	1545/13	2131/6	2584/6	2903/6	3082/4	2890/6	2721/6	2389/2	1784/6	1348/8	1087/14
Long Beach	33.8°	927/37	1214/34	1609/31	1936/30	2063/33	2139/33	2298/27	2098/28	1699/31	1325/33	1003/36	846/38
Los Angeles	33.9°	925/37	1213/34	1618/30	1950/30	2058/33	2118/33	2306/27	2078/28	1680/32	1316/33	1003/36	848/37
Mt. Shasta	41.3°	560/49	857/44	1250/40	1756/33	2180/26	2435/24	2676/18	2212/21	1734/24	1154/31	659/48	505/49
Needles	34.8°	984/30	1353/25	1824/20	2316/16	2650/14	2790/13	2640/19	2276/21	2013/19	1537/21	1123/25	913/30
Oakland	37.7°	707/45	1017/40	1456/33	1921/29	2210/26	2348/27	2321/27	2052/26	1700/29	1211/33	822/40	646/45
Pasadena	34.1°	925/36	1228/33	1618/29	1876/32	2097/32	2138/33	2337/25	2208/23	1777/28	1349/31	999/34	870/38
Point Mugu	34.1°	926/36	1220/33	1634/29	1950/30	2016/34	2053/36	2117/32	1934/33	1607/36	1296/34	1005/34	856/37
Riverside	33.9°	1014/30	1353/27	1762/24	1994/29	2207/25	2507/22	2481/21	2278/21	1972/21	1500/24	1176/24	995/27
Sacramento	38.5°	598/53	939/44	1457/33	2002/25	2433/21	2682/16	2687/14	2367/16	1906/19	1314/27	781/41	538/53
San Diego	32.7°	975/36	1265/33	1631/31	1935/31	2001/36	2061/38	2185/30	2056/29	1716/32	1373/32	1082/33	903/36
San Francisco	37.8°	707/46	1008/40	1454/33	1919/29	2224/26	2375/27	2390/24	2115/25	1741/27	1225/33	821/40	642/45
San Jose	37.3°	863/49	980/42	1301/41	1787/34	2115/31	2207/31	2247/29	1979/31	1691/29	1149/38	956/46	638/47
Santa Maria	34.9°	863/40	1140/37	1581/32	1920/32	2139/32	2347/27	2340/25	2105/27	1729/30	1353/30	973/38	803/38
Sunnyvale	37.4°	737/44	1036/39	1485/32	1943/29	2275/27	2451/24	2440/22	2165/24	1758/27	1248/32	843/39	660/45
COLORADO													
Boulder	40.0°	741/37	988/38	1478/30	1696/37	1696/45	1935/40	1917/39	1618/42	1519/34	1143/34	818/38	671/37
Colo. Springs	38.8°	890/28	1177/28	1549/28	1930/27	2127/31	2367/27	2210/30	2024/29	1758/25	1356/24	944/29	781/30
Denver	39.7°	840/33	1127/30	1530/28	1879/28	2134/30	2360/27	2272/27	2044/28	1726/28	1300/25	883/30	731/33
Eagle	39.6°	754/37	1077/32	1500/30	1931/28	2254/27	2507/22	2385/24	2083/27	1766/24	1307/25	868/32	690/36
Grand Junction	39.1°	791/34	1118/31	1552/28	1985/27	2378/22	2597/20	2464/22	2180/23	1833/22	1344/24	918/30	731/33
Grand Lake	40.3°	782/32	1154/27	1559/25	1888/29	2035/33	2330/28	2212/28	1862/30	1755/24	1331/23	863/31	678/36
Pueblo	38.3°	894/28	1171/30	1563/28	1955/28	2161/30	2433/24	2310/27	2101/27	1778/24	1360/24	953/29	782/31
CONNECTICUT													
Hartford	41.9°	477/56	714/53	978/53	1314/50	1567/48	1685/48	1648/47	1420/49	1154/49	852/48	497/58	384/60
DELAWARE													
Wilmington	39.7°	571/51	827/48	1148/48	1479/45	1709/45	1862/41	1822/42	1613/42	1317/44	984/44	644/50	489/55
DC													
Washington	38.8°	571/54	815/50	1124/48	1458/46	1717/44	1899/41	1817/42	1617/44	1340/44	1003/44	651/50	481/57
FLORIDA													
Apalachicola	29.7°	852/48	1125/45	1473/40	1877/34	2090/32	1997/37	1812/42	1686/42	1534/40	1370/36	1039/40	817/47
Daytona Beach	29.2°	958/42	1213/40	1547/37	1883/34	1966/38	1825/42	1783/42	1681/42	1477/44	1250/42	1035/41	870/45
Gainesville	29.6°	1025/38	1353/33	1640/33	1987/30	2160/30	2006/37	1917/39	1873/38	1637/37	1357/37	1172/32	936/40
Jacksonville	30.4°	899/45	1162/41	1521/37	1854/34	1955/37	1884/41	1801/43	1693/42	1441/44	1222/43	995/41	817/46
Miami	25.8°	1057/42	1313/39	1603/37	1858/38	1842/40	1707/48	1762/44	1629/45	1456/46	1301/42	1117/41	1019/41
Orlando	28.5°	999/41	1242/40	1581/38	1897/33	1987/38	1830/42	1800/43	1672/44	1495/42	1303/40	1095/39	925/42
Pensacola	30.5°	922/44	1183/40	1493/38	1876/33	2072/33	2094/34	1979/37	1876/36	1505/38	1452/31	1025/40	826/46
Tallahassee	30.4°	876/46	1136/42	1478/39	1828/36	1935/38	1882/41	1747/44	1674/42	1492/42	1317/38	1007/41	813/47
Tampa	28.0°	1010/41	1258/40	1593/36	1907/33	1997/36	1847/41	1751/44	1652/44	1491/44	1345/39	1107/38	935/42
GEORGIA													
Atlanta	33.6°	717/51	969/48	1302/44	1685/39	1853/40	1911/40	1811/42	1707/41	1421/42	1199/40	882/44	674/50
Augusta	33.4°	750/49	1014/46	1338/42	1728/38	1864/40	1903/40	1803/42	1666/42	1409/44	1219/39	916/41	720/48
Griffin	33.2°	877/41	1113/40	1430/39	1913/31	2127/31	2138/33	2061/34	1926/33	1611/38	1372/31	1062/32	774/44
Macon	32.7°	709/49	1019/46	1362/42	1734/38	1884/39	1918/40	1784/44	1716/41	1438/42	1246/39	939/41	728/48
Savannah	32.1°	907/41	1158/40	1486/38	1906/32	2075/33	2042/36	1976/37	1847/37	1486/41	1283/38	977/40	789/45
HAWAII													
Hilo	19.7°	1120/40	1246/40	1348/40	1434/40	1553/40	1658/40	1624/45	1592/46	1546/40	1372/40	1104/40	1019/45
Honolulu	21.3°	1180/40	1396/35	1621/35	1796/35	1949/30	2004/30	2002/30	1966/30	1810/30	1540/30	1766/35	1132/35
IDAHO													
Boise	43.6°	485/51	839/41	1302/34	1825/30	2275/25	2461/23	2611/16	2195/21	1736/21	1137/29	628/44	437/51
Pocatello	42.9°	539/48	881/39	1370/32	1819/30	2279/26	2478/23	2598/16	2238/20	1768/21	1202/25	689/39	476/48
Twin Falls	42.5°	601/48	865/44	1309/36	1703/36	2035/33	2183/32	2219/29	1991/29	1593/31	1054/39	649/48	483/54
ILLINOIS													
Chicago	42.0°	506/53	759/49	1106/46	1456/45	1788/41	2006/38	1942/38	1718/38	1353/40	969/41	565/51	402/58
Lemont	41.7°	630/42	855/44	1202/41	1438/46	1632/40	2038/37	1943/38	1702/38	1416/36	977/41	579/51	483/60

[1] Source Data From Klein, Beckman and Duffie, Monthly Average Solar Radiation on Inclined Surfaces, E. Report #42-2, University of Wisconsin, Revised 1978

ASSIGNMENT SHEET #1

INSOLATION AND PERCENT DIFFUSE TABLES, CONTINUED
BTU per sq. ft. per day /% DIFFUSE

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Moline	41.4°	534/51	812/47	1117/46	1458/45	1752/42	1968/39	1937/38	1714/39	1356/40	995/40	594/50	432/56
Peoria	40.7°	601/47	840/46	1187/44	1556/41	1876/39	2112/34	2075/33	1851/34	1500/34	1102/36	682/45	512/50
Springfield	39.8°	585/50	860/46	1133/46	1514/44	1864/39	2096/34	2057/34	1804/36	1453/38	1067/39	676/47	490/54
INDIANA													
Evansville	38.0°	573/55	822/50	1150/47	1500/45	1781/42	1981/38	1919/39	1734/39	1403/41	1087/40	682/50	496/57
Fort Wayne	41.0°	455/59	697/55	981/53	1360/49	1670/46	1840/42	1786/44	1593/44	1272/45	924/46	516/58	369/64
Indianapolis	39.7°	495/58	747/54	1036/51	1397/48	1687/45	1866/42	1805/42	1642/41	1323/44	977/45	579/55	417/62
South Bend	41.7°	416/62	660/56	992/51	1387/47	1721/44	1921/40	1851/41	1665/40	1290/44	909/46	497/58	340/65
IOWA													
Ames	42.0°	642/40	933/38	1205/41	1486/44	1770/42	1994/38	1976/37	1696/39	1353/40	1010/39	689/41	527/46
Des Moines	41.5°	580/47	860/44	1180/42	1556/41	1866/39	2123/34	2096/33	1826/34	1433/37	1067/37	653/46	487/50
Mason City	43.1°	553/46	836/42	1167/41	1517/41	1894/38	2112/34	2083/33	1832/33	1404/37	1010/37	600/47	443/51
Sioux City	42.4°	568/47	841/44	1169/42	1577/40	1900/38	2122/34	2120/32	1344/33	1420/37	1037/37	642/45	469/50
KANSAS													
Dodge City	37.8°	826/36	1121/33	1476/32	1884/31	2089/32	2356/27	2294/27	2054/28	1685/29	1300/29	893/34	732/38
Manhattan	39.2°	708/41	973/40	1272/41	1596/40	1943/37	2031/37	1957/38	1939/31	1512/36	1077/39	837/36	575/48
Topeka	39.1°	681/45	940/42	1256/41	1640/39	1914/38	2125/34	2127/32	1909/32	1515/36	1146/36	771/41	583/47
Wichita	37.8°	783/40	1058/40	1405/35	1782/30	2035/35	2264/30	2238/28	2031/27	1616/30	1249/30	870/35	690/40
KENTUCKY													
Covington	39.1°	372/69	512/68	1036/51	1489/45	1873/39	2142/33	2470/21	2016/28	1471/37	866/51	516/60	299/73
Lexington	38.0°	545/57	779/54	1099/49	1478/48	1746/44	1896/41	1849/41	1685/41	1361/42	1043/42	857/51	485/58
Louisville	38.2°	545/57	789/53	1102/49	1466/46	1719/44	1902/41	1836/41	1679/41	1360/42	1042/42	652/51	488/57
LOUISIANA													
Baton Rouge	30.5°	785/51	1053/47	1378/44	1680/41	1870/39	1925/39	1744/45	1676/42	1463/42	1301/38	919/46	736/51
Lake Charles	30.2°	728/55	1009/49	1313/46	1569/45	1848/40	1969/38	1787/42	1656/44	1484/42	1380/34	916/47	705/54
New Orleans	30.0°	834/49	1111/45	1414/42	1779/38	1966/37	2002/37	1812/42	1715/41	1513/41	1334/37	972/44	779/49
Shreveport	32.4°	833/46	1028/46	1394/41	1721/39	2020/34	2006/37	2072/33	1917/34	1530/38	1312/36	896/45	730/49
MAINE													
Caribou	46.9°	425/50	726/44	1132/39	1407/44	1565/48	1749/46	1749/44	1486/45	1093/48	682/53	368/62	318/57
Portland	43.6°	450/55	682/53	969/51	1303/49	1567/48	1710/47	1658/47	1460/47	1157/47	822/48	459/58	363/58
MARYLAND													
Annapolis	39.0°	645/47	896/45	1254/41	1545/42	1799/41	2053/37	1998/37	1729/39	1411/40	1064/38	697/47	571/48
Baltimore	39.2°	586/51	839/48	1161/46	1487/45	1713/45	1878/41	1822/42	1598/44	1330/44	997/44	660/49	499/55
Silver Hill	38.8°	671/46	900/45	1253/42	1615/40	1891/38	2046/37	1902/39	1692/40	1463/38	1087/39	745/44	600/46
MASSACHUSETTS													
Amherst	42.2°	428/60	652/56	1106/46	1279/51	1589/48	1895/41	1902/39	1622/41	1217/46	922/44	564/51	457/63
Blue Hill	42.2°	575/46	792/47	1121/45	1397/47	1738/44	1906/41	1843/41	1600/40	1298/40	918/45	583/50	476/50
Boston	42.4°	476/55	709/53	1015/50	1325/49	1619/47	1818/44	1748/45	1486/47	1259/44	889/48	503/57	402/57
Lynn	42.5°	435/59	770/48	1106/46	1453/45	1674/45	1983/39	1987/37	1556/44	1253/44	852/48	490/57	369/60
Natick	42.3°	560/47	855/42	1202/41	1441/45	1843/39	1508/54	1891/40	1645/39	1323/41	962/41	542/54	494/48
MICHIGAN													
Detroit	42.2°	417/60	680/54	909/51	1398/47	1714/44	1865/42	1834/41	1574/44	1252/46	875/47	473/60	343/64
East Lansing	42.7°	446/57	774/47	1139/44	1323/49	1780/41	2016/38	1991/37	1718/38	1375/38	940/42	501/56	398/57
Flint	43.0°	383/63	636/56	956/53	1339/49	1657/46	1812/44	1795/42	1554/44	1195/46	829/49	429/62	309/66
Grand Rapids	42.9°	369/64	648/58	1014/49	1411/46	1754/42	1955/39	1913/39	1675/40	1261/44	858/47	446/60	311/66
Lansing	42.8°	498/53	785/46	1135/44	1320/49	1839/39	2038/37	2006/36	1773/36	1390/38	951/41	516/55	413/56
Sault Ste. Marie	46.5°	325/63	603/54	1028/45	1382/45	1687/44	1810/44	1834/41	1522/44	1049/50	673/54	331/66	253/66
Traverse City	44.7°	311/67	567/58	1000/48	1404/46	1728/44	1911/40	1908/39	1608/41	1165/46	754/51	377/64	256/69
MINNESOTA													
Duluth	46.8°	388/55	673/47	1034/45	1372/46	1631/46	1766/45	1853/40	1546/42	1095/48	725/50	380/58	291/60
Internat'l Falls	48.6°	356/54	662/45	1045/41	1442/41	1715/42	1852/42	1920/38	1618/39	1121/45	704/49	345/60	271/58
Minn.-St. Paul	44.9°	464/50	763/45	1102/44	1440/44	1736/42	1927/40	1969/37	1686/39	1254/42	859/44	480/54	353/57
Rochester	43.9°	476/51	752/47	1081/46	1409/46	1694/45	1900/41	1907/39	1661/40	1250/44	869/45	494/55	370/58
St. Cloud	45.6°	627/31	925/31	1349/29	1559/39	1839/39	1994/38	2046/34	1810/33	1327/38	888/41	538/47	453/44
MISSISSIPPI													
Jackson	32.3°	753/51	1026/46	1368/42	1707/39	1940/37	2023/37	1907/39	1780/39	1508/40	1271/38	901/45	708/44
Meridian	32.3°	743/51	1012/47	1327/44	1661/41	1859/40	1961/39	1822/41	1738/40	1453/44	1257/38	896/45	699/51
MISSOURI													
Columbia	39.0°	612/50	874/47	1178/46	1525/44	1878/39	2088/36	2114/32	1876/33	1449/38	1100/38	703/47	522/53
Kansas City	39.3°	647/47	894/45	1202/44	1574/41	1871/39	2078/36	2104/33	1862/34	1451/38	1092/38	737/44	561/49
St. Louis	38.7°	627/49	885/46	1204/45	1563/42	1870/39	2091/36	2048/34	1816/36	1458/38	1099/39	718/46	530/53
Springfield	37.2°	683/48	925/46	1235/45	1603/41	1881/39	2074/36	2061/34	1872/34	1479/38	1143/38	775/45	602/49
MONTANA													
Billings	45.8°	486/46	763/42	1189/38	1525/40	1912/37	2172/32	2382/23	2021/25	1469/31	986/33	561/44	421/47
Dillon	45.2°	526/44	845/37	1279/33	1638/36	1988/34	2142/33	2391/23	2022/25	1520/29	1022/32	601/41	450/45
Glasgow	48.2°	387/50	671/45	1104/39	1487/40	1826/39	2046/37	2192/29	1862/30	1339/34	877/37	478/46	333/50
Great Falls	47.5°	420/49	719/42	1169/37	1487/40	1847/38	2100/34	2327/25	1932/28	1377/33	924/34	498/46	335/53
Helena	46.6°	419/51	708/45	1145/39	1486/41	1859/38	2038/37	2333/25	1929/29	1412/33	925/37	521/46	364/51
Lewiston	47.0°	420/50	692/46	1128/39	1443/42	1806/40	2058/36	2286/27	1900/30	1371/34	904/37	502/47	363/50
Miles City	46.4°	457/47	745/42	1184/37	1541/39	1894/37	2144/33	2296/27	1976/27	1443/31	960/34	550/44	399/47
Missoula	46.9°	312/63	574/55	981/47	1382/45	1781/41	1932/40	2326/25	1880/30	1357/36	812/44	409/57	267/64
Summit	48.3°	450/42	597/50	988/45	1526/38	1703/44	1817/44	2065/33	1880/30	1305/36	796/42	376/57	280/58
NEBRASKA													
Grand Island	41.0°	660/41	917/40	1264/39	1692/37	1971/36	2241/30	2214/29	1938/31	1508/34	1137/33	738/40	569/44
Lincoln	40.8°	700/38	940/39	1279/39	1563/41	1829/40	2009/38	1979/37	1873/33	1519/33	1198/30	763/38	634/38
North Omaha	41.4°	633/42	891/41	1221/41	1558/41	1871/39	2121/34	2105/33	1857/33	1372/40	1049/38	644/47	511/49
North Platte	41.1°	692/38	958/36	1332/36	1723/34	1987/34	2265/30	2275/28	1988/24	1564/31	1176/30	759/38	605/40
Scotts Bluff	41.9°	675/38	950/37	1307/37	1667/37	1932/37	2235/31	2282/28	1998/29	1598/29	1145/31	723/39	575/41
NEVADA													
Elko	40.8°	689/39	1034/33	1462/30	1898/29	2302/24	2532/21	2621/16	2314/18	1891/18	1322/22	812/34	616/40
Ely	39.3°	819/32	1140/30	1605/25	2008/25	2309/24	2511/22	2445/22	2229/21	1934/19	1407/21	925/29	722/34

ASSIGNMENT SHEET #1

INSOLATION AND PERCENT DIFFUSE TABLES, CONTINUED
BTU per ft. per day /% DIFFUSE

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Las Vegas	36.1°	977/28	1336/23	1822/19	2318/15	2644/14	2776/13	2587/18	2353/18	2036/18	1538/19	1085/25	880/30
Lovelock	40.1°	803/31	1165/27	1655/22	2164/19	2553/16	2747/15	2782/12	2482/12	2026/12	1450/16	929/27	714/32
Reno	39.5°	800/33	1149/29	1548/23	2158/20	2521/16	2700/16	2690/14	2404/16	1996/14	1430/19	911/30	705/34
Tonopah	38.1°	918/28	1273/23	1776/19	2250/18	2576/16	2786/13	2701/14	2437/14	2041/14	1520/16	1030/24	826/29
Winnemucca	40.9°	690/39	1027/33	1471/30	1966/25	2360/23	2568/20	2676/14	2347/16	1906/16	1321/22	809/34	618/39
NEW HAMPSHIRE													
Concord	43.2°	459/55	686/53	973/51	1316/49	1581/48	1704/47	1673/47	1455/47	1139/48	816/48	462/58	362/60
NEW JERSEY													
Atlantic City	39.4°	652/46	940/41	1419/33	[illegible]93/40	1817/41	2112/34	2094/33	175[illegible]/38	1445/38	1103/37	778/40	586/46
Lakehurst	40.0°	559/53	796/49	1108/48	1455/46	1671/46	1773/46	1702/48	[illegible]31/46	1260/48	955/45	621/51	475/56
Newark	40.7°	551/51	793/49	1108/47	1448/46	1686/45	1794/46	1758/44	1564/45	1272/45	950/45	596/51	454/56
Trenton	40.2°	638/45	900/42	1264/40	1563/41	1810/41	2013/38	1991/37	1729/39	1434/38	1084/38	719/42	571/46
NEW MEXICO													
Albuquerque	35.0°	1018/28	1341/25	1766/23	2227/20	2537/18	2677/18	2487/21	2289/21	1971/20	1545/20	1133/24	1927/29
Farmington	36.7°	944/29	1280/25	1692/24	2132/22	2450/21	2664/18	2477/21	2251/21	1933/20	1478/21	1046/27	837/31
Roswell	33.4°	1046/30	1372/27	1806/23	2216/21	2458/21	2608/19	2439/22	2240/23	1912/23	1526/23	1131/28	951/31
Zuni	35.1°	965/30	1296/28	1686/2[illegible]	2185/22	2472/20	2600/19	2263/28	2077/28	1893/23	1495/23	1087/28	892/31
NEW YORK													
Albany	42.7°	502/53	766/48	1104/46	1493/42	1760/42	1950/39	1957/37	1699/39	1316/41	918/44	525/54	399/57
Binghamton	42.2°	386/64	575/62	860/58	1241/53	1493/51	1680/48	1658/47	1424/49	1131/49	778/53	414/65	297/68
Buffalo	42.9°	349/68	546/63	858/56	1314/49	1596/48	1806/44	1776/44	1512/46	1151/48	784/51	403/64	284/69
Ithaca	42.4°	450/57	748/49	1040/49	1283/51	1729/44	1987/38	1972/37	1696/39	1312/41	914/45	461/60	365/62
Massena	44.9°	431/54	692/49	1095/44	1500/41	1808/40	2006/38	1987/37	1687/38	1267/41	830/46	448/57	330/60
New York	40.8°	500/56	720/54	1036/50	1363/49	1635/47	1709/47	1686/46	1482/47	1213/47	895/48	533/57	403/60
Rochester	43.1°	364/65	569/62	903/55	1338/48	1605/47	1816/44	1780/44	1518/45	1159/48	781/51	403/64	281/69
Schenectady	42.8°	479/54	741/49	1010/50	1253/51	1526/50	1655/49	1637/48	1471/47	1106/50	807/50	476/58	383/58
Syracuse	43.1°	385/63	571/60	890/56	1323/49	1577/48	1777/45	1757/44	1502/46	1165/48	777/51	398/65	285/68
NORTH CAROLINA													
Asheville	35.4°	721/48	970/46	1305/42	1660/40	1803/41	1854/42	1775/44	1626/44	1360/45	1146/40	848/42	657/49
Cape Hatteras	35.3°	685/51	952/47	1325/41	1773/36	1960/37	2035/37	1919/39	1705/41	1470/40	1136/41	873/41	659/49
Charlotte	35.2°	719/48	970/46	1314/42	1694/39	1854/40	1920/40	1830/41	1694/41	1415/42	1173/39	865/42	672/50
Cherry Point	34.9°	756/47	1024/44	1386/39	1793/36	1923/38	1937/39	1828/41	1633/44	1433/42	1169/40	906/40	718/45
Greensboro	36.1°	715/47	969/45	1312/41	1662/39	1867/39	1952/39	1862/40	1695/41	1417/41	1140/40	838/42	658/47
Raleigh	35.8°	693/48	942/47	1275/44	1643/40	1807/41	1863/42	1774/44	1610/44	1376/44	1104/42	812/45	635/49
Raleigh-Durham	35.9°	793/42	1043/41	1379/38	1780/36	1905/38	1976/39	2038/36	1773/38	1463/40	1165/39	885/39	719/42
NORTH DAKOTA													
Bismarck	46.8°	467/48	775/39	1168/38	1458/42	1847/39	2059/36	2182/30	1876/31	1353/36	907/38	507/47	372/49
Fargo	46.9°	415/51	705/46	1097/41	1475/41	1833/39	1993/38	2119/32	1824/32	1303/38	874/39	457/51	337/54
Minot	48.2°	383/51	655/46	1043/42	1460/41	1845/38	1973/39	2097/32	1799/32	1276/38	849/39	439/50	310/54
OHIO													
Akron	40.9°	428/62	649/58	963/54	1356/49	1667/46	1838/44	1786/44	1595/44	1271/45	907/47	505/59	353/65
Cleveland	41.4°	388/65	601/60	922/56	1349/49	1680/45	1842/42	1826/41	1581/44	1239/46	866/48	466/62	318/68
Columbus	40.0°	459/60	676/57	979/54	1352/49	1646/49	1811/44	1754/45	1640/42	1279/45	949/46	537/57	387/64
Dayton	39.9°	489/50	725/55	1025/51	1402/48	1699/45	1872/42	1809/42	1644/41	1317/44	969/45	564/56	407/62
Put-in-Bay	41.6°	442/58	734/51	1077/48	1360/48	1821/40	1998/38	2090/33	1902/32	1471/34	1087/34	579/51	409/58
Toledo	41.6°	435/60	680/55	996/51	1383/48	1715/44	1877/41	1848/41	1615/42	1275/44	910/46	498/58	355/64
Youngstown	41.3°	385/65	586/62	889/57	1278/51	1585/48	1758/46	1733/45	1506/46	1193/48	851/49	456/63	315/68
OKLAHOMA													
Oklahoma City	35.4°	800/42	1054/41	1399/38	1724/38	1917/38	2142/33	2127/32	1949/32	1553/27	1232/38	901/39	725/44
Stillwater	36.1°	763/44	1054/40	1430/37	1681/39	1851/40	2186/32	2166/30	1996/30	1677/31	1268/31	947/34	752/40
Tulsa	36.2°	731/46	977/45	1305/42	1602/41	1821/41	2019/37	2029/36	1864/34	1471/39	1163/39	827/42	659/47
OREGON													
Astoria	46.2°	314/64	545/58	866/54	1252/50	1607/47	1625/49	1745/44	1498/45	1183/45	712/51	387/60	261/66
Burns	43.6°	490/51	792/45	1186/40	1646/37	2051/32	2276/29	2459/21	2082/24	1619/27	1042/34	593/46	431/51
Corvallis	44.5°	500/48	738/47	1027/47	1397/46	1671/45	1836/44	1770/44	1633/40	1310/40	989/38	588/45	432/49
Medford	42.4°	407/62	737/50	1132/45	1636/38	2032/33	2276/29	2473/21	2120/24	1588/29	981/40	504/56	336/65
North Bend	43.4°	439/57	704/50	1058/47	1508/42	1856/39	1993/38	2106/32	1785/38	1376/38	892/44	524/53	380/58
Pendleton	45.7°	348/62	613/54	1043/46	1501/41	1924/37	2143/33	2394/23	1993/27	1501/30	908/39	438/56	292/63
Portland	45.6°	310/66	554/58	895/54	1307/49	1662/45	1772/45	2036/34	1672/39	1216/44	723/51	387/62	260/67
Redmond	44.3°	490/45	774/45	1190/39	1682/34	2078/31	2286/29	2444/22	2068/24	1583/28	999/36	571/47	424/50
Salem	44.9°	332/65	587/57	947/51	1369/47	1796/42	1847/42	2141/31	1773/36	1328/39	769/50	410/60	277/66
PENNSYLVANIA													
Allentown	40.6°	527/54	783/51	1078/48	1409/47	1636/47	1776/45	1764/44	1545/45	1237/46	925/46	568/54	430/58
Avoca	41.3°	454/59	688/55	991/53	1338/49	1589/48	1758/46	1744/45	1512/46	1198/47	896/47	490/59	368/63
Erie	42.1°	345/68	577/62	919/55	1358/48	1645/46	1846/42	1832/41	1454/48	1200/47	827/50	416/65	277/71
Harrisburg	40.2°	535/54	770/51	1082/49	1410/47	1651/46	1803/44	1762/44	1550/45	1265/45	933/46	579/54	447/57
Philadelphia	39.9°	555/53	794/50	1108/48	1433/47	1659/46	1810/44	1757/44	1574/45	1280/45	958/45	619/51	470/56
Pittsburgh	40.5°	424/62	625/60	942/53	1316/50	1601/48	1761/46	1689/46	1510/46	1208/48	895/48	504/59	346/66
State College	40.8°	512/55	745/51	1095/48	1375/48	1721/44	2006/38	1947/38	1674/40	1331/42	1014/40	571/54	442/57
RHODE ISLAND													
Newport	41.5°	571/48	852/44	1217/41	1456/45	1803/41	1963/39	1817/39	1655/41	1401/38	1006/40	645/46	520/48
Providence	41.7°	506/54	738/51	1031/50	1373/48	1654/46	1774/45	1694/46	1498/47	1208/47	906/46	537/55	418/57
SOUTH CAROLINA													
Charleston	32.9°	744/50	995/47	1338/44	1731/38	1859/40	1843/42	1798/42	1584/46	1393/45	1192/41	933/41	720/48
Columbia	33.9°	761/48	1020/45	1354/41	1745/37	1893/39	1946/39	1840/41	1701/41	1438/42	1211/39	920/40	721/47
Grnvle.-Sptnbrg	34.9°	729/49	981/46	1328/41	1697/39	1838/39	1918/39	1830/40	1699/40	1405/42	1180/34	880/40	670/49
SOUTH DAKOTA													
Huron	44.4°	488/49	744/47	1113/44	1529/40	1870/38	2100/34	2181/30	1891/31	1417/34	988/37	577/46	405/53
Pierre	44.4°	529/45	794/42	1205/38	1613/38	1965/36	2193/32	2277/27	1991/28	1495/31	1051/32	623/41	442/48

ASSIGNMENT SHEET #1

INSOLATION AND PERCENT DIFFUSE TABLES, CONTINUED
BTU per ft. per day/% DIFFUSE

City	Lat.	Jan.	Feb.	Mar	Apr	May	June	July	Aug.	Sept	Oct	Nov.	Dec.
Rapid City	44.1°	542/45	826/41	1228/38	1588/38	1885/38	2130/33	2222/29	1961/29	1517/31	1063/32	646/40	476/45
Sioux Falls	43.6°	532/47	801/44	1152/42	1542/40	1892/38	2098/34	2149/31	1843/33	1409/38	1005/37	607/45	441/50
TENNESSEE													
Chattanooga	35.0°	630/53	858/53	1176/48	1549/44	1730/44	1830/42	1734/45	1629/44	1335/46	1108/42	772/48	580/55
Memphis	35.0°	682/51	944/48	1277/44	1638/41	1884/39	2043/37	1971/37	1823/37	1470/40	1204/38	816/46	628/51
Nashville	36.0°	601/65	882/59	1188/56	1638/49	1911/46	2081/43	2033/43	1845/44	1561/44	1199/46	808/57	605/60
Oak Ridge	36.0°	612/55	877/50	1202/47	1648/40	1898/38	2009/38	1921/39	1755/39	1537/37	1176/38	778/47	593/53
TEXAS													
Abilene	32.4°	923/40	1182/38	1575/33	1842/34	2036/34	2208/31	2138/32	1955/32	1596/37	1313/36	1007/38	863/39
Amarillo	35.2°	960/31	1242/31	1630/29	2017/27	2210/29	2392/25	2279/28	2102/27	1759/28	1403/28	1032/31	871/32
Big Spring	32.2°	988/36	1268/33	1718/28	2126/23	2109/32	2186/31	2035/34	1725/41	1928/23	1423/30	1073/33	958/33
Brownsville	25.9°	912/50	1135/47	1456/42	1736/40	1926/38	2114/32	2211/29	2026/31	1692/37	1438/37	1054/46	862/50
Corpus Christi	27.8°	897/48	1146/45	1437/42	1641/42	1865/39	2092/33	2184/30	1989/32	1686/38	1415/36	1072/42	844/48
Dallas	32.8°	821/46	1071/44	1421/40	1626/42	1887/39	2134/33	2120/32	1949/33	1586/37	1275/37	936/41	779/45
El Paso	31.8°	1124/28	1479/23	1908/20	2362/16	2599/16	2680/16	2449/22	2283/22	1986/22	1638/21	1243/24	1030/29
Fort Worth	32.8°	800/47	1063/44	1401/40	1610/42	1882/39	2145/33	2146/31	1972/32	1610/38	1276/37	926/42	757/46
Houston	30.0°	772/53	1034/48	1296/47	1522/47	1773/42	1897/40	1827/41	1685/42	1470/42	1275/40	924/47	729/53
Kingsville	27.5°	911/48	1161/45	1434/42	1662/42	1863/39	2035/36	2110/32	1921/34	1624/38	1389/37	1034/44	849/48
Lubbock	33.6°	1030/30	1331/29	1761/24	2166/22	2394/22	2543/21	2410/23	2207/24	1819/27	1467/27	1116/29	934/31
Lufkin	31.2°	793/50	1068/46	1375/42	1623/42	1865/40	2054/36	2005/36	1862/36	1529/40	1348/38	962/42	767/48
Midland	31.9°	1080/30	1382/29	1838/23	2191/22	2429/21	2561/20	2388/23	2208/24	1843/28	1521/[illegible]	1176/28	999/31
Port Arthur	29.9°	800/51	1070/47	1353/45	1609/44	1869/39	2009/37	1845/41	1735/41	1526/41	1321/38	952/45	754/51
San Angelo	31.4°	961/39	1207/38	1605/33	1849/34	2030/34	2185/31	2121/32	1965/32	1606/37	1336/38	1043/37	894/39
San Antonio	29.5°	895/46	1154/44	1449/41	1611/44	1893/39	2068/34	2120/32	1946/33	1634/37	1349/37	1008/42	846/46
Waco	31.6°	832/47	1095/44	1427/40	1611/42	1773/42	2111/33	2129/32	1957/33	1600/37	1301/37	956/42	802/45
Wichita Falls	34.0°	861/41	1122/39	1471/37	1762/37	2016/34	2220/31	2165/31	1968/32	1601/36	1291/34	956/38	799/41
UTAH													
Cedar City	37.7°	881/31	1179/30	1634/25	2091/23	2466/20	2704/16	2502/20	2240/21	1967/18	1459/21	992/28	785/33
Salt Lake City	40.8°	638/44	988/37	1453/30	1893/29	2361/23	2559/21	2588/18	2252/20	1842/20	1293/24	787/36	570/45
VERMONT													
Burlington	44.5°	425/56	678/51	1055/46	1449/44	1766/41	1949/39	1950/38	1672/39	1264/42	834/48	433/59	320/63
VIRGINIA													
Mt. Weather	39.1°	634/48	1010/38	1246/42	1526/44	1873/39	1935/40	1880/40	1585/44	1382/42	1036/41	745/44	619/44
Norfolk	36.9°	678/49	932/46	1280/42	1676/39	1886/39	1999/38	1852/41	1679/41	1395/41	1082/41	811/41	623/48
Richmond	37.8°	631/50	876/48	1210/45	1565/42	1761/42	1871/42	1773/44	1599/44	1347/44	1032/44	733/47	566/51
Roanoke	37.3°	660/49	899/47	1235/45	1581/42	1763/42	1881/41	1795/42	1619/44	1357/44	1080/41	764/45	590/50
WASHINGTON													
Olympia	47.0°	269/68	503/60	844/55	1255/50	1631/46	1692/47	1912/39	1548/42	1156/45	636/56	339/64	221/69
Prosser	46.2°	431/50	818/37	1294/31	1921/24	2271/24	2507/22	2606/16	2227/18	1689/20	1010/31	501/48	369/51
Pullman	46.7°	453/47	671/48	1095/41	1681/33	1998/33	2529/21	2603/16	2035/24	1578/24	944/34	542/44	354/53
Richland	46.3°	317/64	741/44	1228/34	1721/32	1902/37	2385/25	2124/32	2216/19	1430/32	844/42	457/53	365/53
Seattle	47.4°	288/65	501/59	973/47	1460/41	1847/38	1921/40	2090/32	1685/38	1209/41	697/51	391/57	236/67
Spokane	47.7°	314/62	606/51	1040/44	1494/40	1917/36	2082/38	2355/24	1941/28	1434/31	840/40	397/56	255/64
Tacoma	47.2°	262/68	495/60	849/54	1293/48	1713/42	1801/44	2246/28	1615/40	1146/45	656/54	337/64	211/71
Whidbey Is.	48.3°	293/65	532/55	917/50	1345/45	1760/40	1820/45	1981/35	1592/40	1173/40	655/53	357/60	233/67
WEST VIRGINIA													
Charleston	38.4°	498/60	706/57	1009/54	1355/50	1639/47	1774/45	1682/47	1514/47	1272/46	971/46	613/55	440/62
Parkersburg	39.3°	527/56	745/54	1113/48	1397/48	1795/41	1994/38	1939/38	1784/37	1453/38	1047/41	616/53	487/56
WISCONSIN													
Eau Claire	44.9°	452/53	746/46	1089/44	1425/45	1680/45	1870/42	1885/40	1619/41	1196/45	826/46	450/57	341/59
Green Bay	44.5°	451/53	725/48	1103/44	1438/44	1718/44	1906/41	1887/39	1621/41	1217/44	820/47	465/56	350/59
La Crosse	43.9°	481/51	764/46	1100/45	1426/45	1712/44	1904/41	1899/39	1665/40	1242/44	893/46	494/55	369/58
Madison	43.1°	515/50	803/45	1135/44	1397/46	1742/42	1947/40	1933/38	1707/38	1299/41	910/44	504/55	388/57
Milwaukee	42.9°	479/54	736/49	1088/46	1441/45	1767/42	1976/39	1960/38	1718/38	1309/41	907/44	524/54	378/58
WYOMING													
Casper	42.9°	682/34	1013/30	1441/29	1846/29	2202/28	2500/22	2533/19	2224/20	1749/21	1218/24	764/32	593/36
Cheyenne	41.1°	765/31	1067/30	1432/31	1769/33	1994/34	2257/30	2229/29	1965/30	1666/27	1241/27	822/32	671/33
Lander	42.8°	848/19	1183/19	1662/18	2038/22	2156/29	2488/23	2389/23	2138/23	1711/23	1312/19	874/23	726/22
Laramie	41.3°	826/25	1099/28	1563/24	1836/31	2020/33	2311/29	2186/30	1939/31	1548/32	1176/30	837/31	675/32
Rock Springs	41.6°	734/33	1088/28	1530/25	1943/27	2343/23	2573/20	2546/19	2238/20	1832/19	1305/22	826/31	650/34
Sheridan	44.8°	517/45	787/42	1204/38	1537/40	1882/38	2155/33	2327/25	2005/27	1500/31	1005/34	590/44	441/47
ALBERTA													
Edmonton	53.6°	328/39	649/32	1150/28	1522/34	1876/35	1891/41	1939/37	1508/41	1099/40	593/39	409/36	245/44
Lethbridge	49.6°	442/38	774/32	1253/29	1548/37	1917/36	2138/33	2249/28	1917/28	1364/31	885/33	516/37	332/46
BRITISH COLUMBIA													
Vancouver	49.0°	280/63	383/67	689/62	1264/48	1725/42	1777/45	2009/36	1467/45	929/54	590/56	350/58	206/67
MANITOBA													
Churchill	58.7°	240/23	553/23	1124/18	1640/24	1880/33	1954/38	1862/38	1401/42	829/49	424/53	221/45	129/42
Winnipeg	49.9°	483/31	829/27	1338/23	1618/33	1880/37	1935/40	2094/32	1740/34	1179/41	756/42	439/46	339/44
NEW BRUNSWICK													
Moncton	46.1°	369/58	664/51	1069/44	1401/45	1622/46	1659/48	1733/45	1512/45	1143/46	774/48	405/58	332/57
NEWFOUNDLAND													
St. Johns	47.5°	295/64	553/56	885/51	1180/53	1475/50	1585/50	1622/48	1253/54	1032/50	627/56	295/67	258/64
ONTARIO													
Ottawa	45.4°	531/42	841/37	1235/36	1486/41	1832/39	2057/36	2016/36	1729/37	1309/39	815/46	453/55	402/50
Sapuskasing	49.4°	405/45	700/39	1143/34	1364/45	1512/49	1770/45	1770/42	1475/45	995/50	590/56	295/64	295/53
Toronto	43.7°	446/55	682/51	1077/46	1372/47	1762/42	1917/40	1943/38	1600/42	1268/42	826/48	453/58	350/60
QUEBEC													
Montreal	45.5°	405/56	737/45	1180/38	1435/42	1733/42	1806/44	1880/40	1622/40	1143/47	737/51	369/64	295/63

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COLLECTOR TILT FACTORS

		LATITUDE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
20% Diffuse	COLLECTOR TILT = LAT. − 15	24	1.13	1.09	1.04	1.00	0.97	0.96	0.97	1.00	1.04	1.10	1.12	1.15
		32	1.34	1.24	1.11	0.99	0.93	0.94	0.92	0.98	1.11	1.28	1.34	1.42
		40	1.67	1.41	1.23	1.01	0.90	0.90	0.89	1.02	1.21	1.42	1.73	1.76
		48	2.16	1.64	1.51	1.10	0.96	0.80	0.95	1.08	1.43	1.73	2.26	2.56
	COLLECTOR TILT = LATITUDE	24	1.31	1.21	1.08	0.95	0.87	0.85	0.87	0.94	1.08	1.21	1.28	1.37
		32	1.56	1.39	1.16	0.97	0.79	0.76	0.78	0.96	1.15	1.45	1.56	1.71
		40	1.95	1.55	1.28	0.98	0.75	0.75	0.74	1.00	1.25	1.57	2.05	2.10
		48	2.53	1.80	1.57	1.08	0.90	0.74	0.89	1.05	1.49	1.90	2.63	3.04
	COLLECTOR TILT = LAT. + 15	24	1.40	1.25	1.06	0.80	0.70	0.67	0.70	0.79	1.05	1.27	1.36	1.50
		32	1.69	1.45	1.13	0.89	0.59	0.55	0.58	0.88	1.12	1.54	1.68	1.89
		40	2.11	1.60	1.25	0.91	0.67	0.65	0.66	0.92	1.23	1.63	2.24	2.30
		48	2.72	1.85	1.54	1.00	0.79	0.65	0.78	0.97	1.45	1.98	2.84	3.3[illegible]
40% Diffuse	COLLECTOR TILT = LAT. − 15	24	1.10	1.07	1.03	1.00	0.97	0.96	0.97	1.00	1.03	1.07	1.09	1.12
		32	1.27	1.20	1.09	0.96	0.93	0.95	0.92	0.97	1.09	1.22	1.26	1.33
		40	1.52	1.33	1.18	0.96	0.89	0.89	0.89	1.00	1.16	1.34	1.59	1.61
		48	1.93	1.50	1.42	1.06	0.94	0.78	0.93	1.04	1.35	1.57	2.02	2.23
	COLLECTOR TILT = LATITUDE	24	1.24	1.16	1.06	0.95	0.88	0.86	0.88	0.94	1.05	1.17	1.21	1.28
		32	1.44	1.31	1.12	0.96	0.79	0.76	0.78	0.95	1.11	1.36	1.43	1.56
		40	1.74	1.44	1.21	0.96	0.74	0.74	0.73	0.97	1.19	1.46	1.84	1.87
		48	2.20	1.61	1.45	1.03	0.88	0.73	0.87	1.01	1.38	1.71	2.31	2.60
	COLLECTOR TILT = LAT. + 15	24	1.32	1.19	1.03	0.80	0.72	0.69	0.72	0.79	1.03	1.20	1.26	1.38
		32	1.53	1.36	1.09	0.89	0.59	0.56	0.58	0.88	1.08	1.42	1.52	1.70
		40	1.85	1.47	1.18	0.88	0.67	0.66	0.66	0.90	1.15	1.50	1.98	2.03
		48	2.34	1.64	1.41	0.95	0.78	0.64	0.77	0.93	1.34	1.75	2.46	2.82
60% Diffuse	COLLECTOR TILT = LAT. − 15	24	1.07	1.05	1.02	1.00	0.98	0.97	0.98	0.99	1.02	1.05	1.06	1.09
		32	1.20	1.15	1.06	0.97	0.93	0.95	0.92	0.96	1.06	1.17	1.19	1.25
		40	1.38	1.25	1.13	0.96	0.88	0.89	0.88	0.98	1.12	1.26	1.45	1.46
		48	1.69	1.35	1.33	1.02	0.92	0.77	0.91	1.00	1.27	1.42	1.77	1.90
	COLLECTOR TILT = LATITUDE	24	1.17	1.11	1.04	0.94	0.89	0.87	0.89	0.93	1.03	1.12	1.13	1.20
		32	1.31	1.24	1.07	0.94	0.79	0.76	0.78	0.94	1.07	1.26	1.30	1.41
		40	1.53	1.32	1.14	0.93	0.73	0.74	0.73	0.95	1.12	1.35	1.63	1.65
		48	1.87	1.42	1.34	0.99	0.86	0.72	0.85	0.97	1.28	1.51	1.98	2.16
	COLLECTOR TILT = LAT. + 15	24	1.22	1.13	1.00	0.80	0.73	0.71	0.73	0.79	1.00	1.13	1.16	1.25
		32	1.37	1.26	1.04	0.88	0.59	0.56	0.58	0.87	1.03	1.30	1.36	1.50
		40	1.60	1.34	1.10	0.86	0.66	0.66	0.66	0.88	1.08	1.37	1.72	1.76
		48	1.96	1.43	1.29	0.91	0.77	0.64	0.76	0.89	1.23	1.52	2.09	2.31
80% Diffuse	COLLECTOR TILT = LAT. − 15	24	1.04	1.03	1.01	1.00	0.98	0.97	0.98	0.99	1.01	1.03	1.04	1.05
		32	1.12	1.11	1.04	0.96	0.93	0.96	0.92	0.96	1.04	1.11	1.12	1.16
		40	1.24	1.17	1.08	0.94	0.88	0.88	0.87	0.96	1.07	1.18	1.30	1.31
		48	1.44	1.22	1.24	0.96	0.90	0.75	0.89	0.97	1.19	1.27	1.53	1.57
	COLLECTOR TILT = LATITUDE	24	1.10	1.07	1.01	0.94	0.90	0.89	0.90	0.93	1.01	1.07	1.06	1.11
		32	1.19	1.16	1.03	0.93	0.79	0.77	0.78	0.93	1.03	1.17	1.18	1.26
		40	1.33	1.21	1.07	0.90	0.73	0.74	0.72	0.93	1.06	1.23	1.42	1.43
		48	1.55	1.25	1.22	0.94	0.84	0.70	0.84	0.93	1.18	1.31	1.66	1.72
	COLLECTOR TILT = LAT. + 15	24	1.12	1.06	0.98	0.80	0.75	0.73	0.75	0.79	0.97	1.06	1.05	1.13
		32	1.21	1.17	0.99	0.87	0.60	0.57	0.59	0.86	0.99	1.18	1.19	1.31
		40	1.35	1.20	1.02	0.83	0.66	0.66	0.65	0.86	1.01	1.24	1.47	1.49
		48	1.58	1.23	1.16	0.87	0.76	0.63	0.75	0.85	1.12	1.29	1.71	1.79

ASSIGNMENT SHEET #1

STUDENT WORKSHEET

CDA SUN-CHART CALCULATION WORKSHEET

JOB:
LOCATION:
LATITUDE:

COLLECTOR TYPE:
COLLECTOR TILT:
APPLICATION:

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG S LIT	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG S LIT	AVERAGE DAYTIME AIR TEMPERATURE F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) F	H COLUMN G COLUMN C F	J $\frac{B}{A}$ x2H	K $\frac{J}{F}$	L IS FOUND FROM FIGURE 41 USING K	TOTAL ENERGY COLLECTED = F x L BTU SQ FT DAY
JANUARY												
FEBRUARY												
MARCH												
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER												

Worksheets are available upon request from Copper Development Assn. Inc.

Courtesy Copper Development Association Inc.

LOAD CALCULATIONS AND SOLAR COOLING
UNIT III

ASSIGNMENT SHEET #2--SIZE A SOLAR COLLECTOR FOR A COMBINATION DHW AND SPACE HEATING SOLAR SYSTEM

Directions: Refer to the completed CDA sun-chart worksheet in Assignment Sheet #1 for references to help you fully understand the following example of how to size a solar collector; remember, the worksheet must be completed before the sizing procedure can begin.

Step 1: List all parameters of the application:

Location: Nashville, Tennessee
Latitude: 36° North
Collector type: Double glazed with selective surface
Collector tile: 51°
Combined space and water heating requirements; this can be interpolated from the chart in Figure 1

FIGURE 1

	[1] TOTAL SPACE & DWH HEAT REQUIRED (BTU/DAY)	[2] USABLE COLLECTOR PRODUCTION FOR VARIOUS COLLECTOR AREAS (BTU/DAY)		
		500 SQ.FT.	400 SQ.FT.	350 SQ.FT.
January	390,000	181,500	145,200	127,050
February	364,200	252,500	202,000	176,750
March	275,200	272,000	217,600	190,400
April	135,870	(135,870)[3]	(135,870)	(135,870)
May	68,950	(68,950)	(68,950)	(68,950)
June	50,000	(50,000)	(50,000)	(50,000)
July	48,500	(48,500)	(48,500)	(48,500)
August	45,500	(45,500)	(45,500)	(45,500)
September	58,400	(58,400)	(58,400)	(58,400)
October	114,250	(114,250)	(114,250)	(114,250)
November	271,250	(271,250)	223,200	195,300
December	366,800	217,000	173,600	151,900
	2,188,920	1,715,720	1,483,070	1,362,870
Percent of Annual Load Supplied by Solar		78%	68%	62%

[1] Sum of Tables 6 and 7

[2] **Products of energy collected (BTU/sq. ft./day) x collector area**

[3] Numbers in parentheses are the *useful* solar energy, when the calculated production is greater than the requirement

Step 2: Complete the CDA sun-chart worksheet as directed in Assignment Sheet #1

Step 3: From the completed sun-chart worksheet, find the amount of heat available from the collector during the month of March; in the completed worksheet, this figure is 544

ASSIGNMENT SHEET #2

Step 4: Find the combined space and water heating requirement for the month of March; in the completed worksheet, this figure is 275,200 Btu/day

(NOTE: This figure must be interpolated from the chart in Figure 1, Assignment Sheet #2.)

Step 5: Make a preliminary estimate of required collector area by dividing 544 into 275,200; the answer is about 500 square feet

Step 6: Make a numerical check of estimated collector area by dividing the total solar heat collected (1,715,720 Btu from the chart in Figure 1) by the annual heat requirement (2,188,920 from the chart in Figure 1).

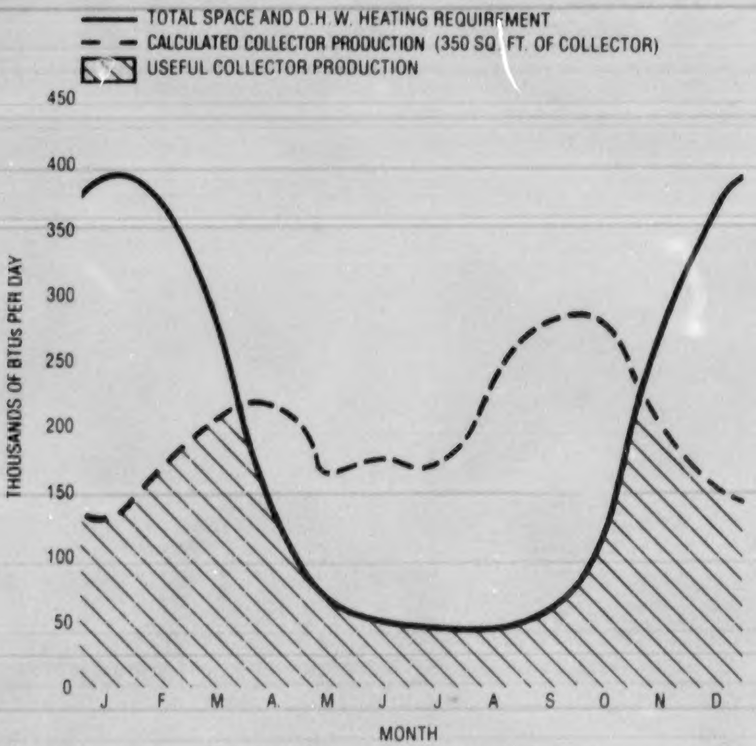
Example: In any month, only that portion of the collectable energy which can be applied to the load is considered; in May when only 68,950 Btu/day are required, only this portion of the available solar heat is applied to the load

For the sample Nashville application, the estimated collector area of 500 square feet would supply 78% of the annual load (see the chart in Figure 1). Since this is higher than desired, an adjusted collector area of 400 feet should be considered. This yields a result of 68% of the total load supplied by solar energy, and is consistent with the recommended guidelines of 60 to 70 percent. Another trail can be made using 350 square feet of collector area. This yields 62% of the annual heating requirement, so the collector selected should be between 350 and 400 square feet

ASSIGNMENT SHEET #2

Step 7: Check your calculations by drawing a graph to show the amount of useful solar heat produced by the square footage of the collector area; in the example in Figure 2, this availability of useful solar heat is indicated by the shaded area and is based on 350 square feet of collector area

FIGURE 2



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Assignment: Refer to the worksheet you completed in Assignment Sheet #1 and size a collector for the application assigned for that activity; interpolate from the chart in Figure 1 as required or make new entries for Btu/day requirements as your personal worksheet dictates; sketch a graph to check your calculations and model it after the graph in Figure 2.

LOAD CALCULATIONS AND SOLAR COOLING
UNIT III

NAME ______________________________

TEST

1. Match the terms on the right with their correct definitions.

_____a. British thermal unit; the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit

_____b. British thermal units per hour; unit used to express hourly heat flow

_____c. The air temperature as measured by an ordinary thermometer

_____d. The air temperature as measured by a thermometer whose bulb is covered with a wet cloth or wet wick and moved in air that has a velocity of one thousand feet per minute

_____e. The amount of heat lost through all building surfaces, walls, floors, doors, and windows exposed to outdoors or to adjoining spaces with different temperatures

_____f. The amount of heat gained through all building surfaces, walls, floors, doors, and windows exposed to outdoors or from adjoining spaces with different temperatures

_____g. The total heat loss and heat gain of a structure expressed in Btuh; this calculation is used to size heating and cooling equipment

_____h. Controlled air brought into a structure

_____i. Uncontrolled air that leaks into a structure

_____j. The amount of water vapor or moisture that is present in the atmosphere or any material

_____k. The percentage of moisture in the air compared to the total amount of moisture the air could hold at the same temperature and barometric pressure

_____l. The science of measuring and changing the properties of air

1. Psychometrics
2. R-value
3. Load
4. Heat loss
5. Btuh
6. Dry-bulb temperature
7. Cfm
8. Nomogram
9. Refrigerant
10. Wet-bulb temperature
11. Absorbent
12. Heat gain

_____m. The science of heating and cooling with liquids

_____n. A chart which can be used with a straightedge to determine the square footage requirements of a collector

_____o. A substance used in refrigerating mechanisms to absorb heat in the evaporator

_____p. A liquid which combines chemically with a refrigerant and causes heat to be released in the process of combination

_____q. The rating given to a material's ability to resist heat transfer

_____r. Cubic feet per minute

_____s. A refrigerating effect equal to 12,000 Btuh

_____t. The component in an absorption cooling unit which absorbs heat from the circulating water supply

13. Ton of refrigeration
14. Ventilation
15. Hydronics
16. Humidity
17. Btu
18. Relative humidity
19. Infiltration
20. Chiller

2. Solve the following problem concerning considerations for establishing heat requirements for solar water heating: An application for a solar hot water heating system will have a water supply from a deep well; will this make the task of determining the temperature of the inlet water supply easier or more difficult, and why?

____

____

3. Solve the following problem concerning the concept of degree days and its formula: The mean temperature on a given day is 47°F; what would be the number of degree days for this specific calendar day? _______________________

4. Solve the following problem concerning the concept of the degree day adjustment factor and its application: If the heating requirement for a given solar system application has been established at 28,000 Btuh, and the degree day adjustment factor has been established at 1.7, what would the adjusted heating requirements be?

____

____

____

5. Solve the following problem concerning the sun-chart worksheet and its applications: Use of the sun-chart worksheet assumes certain characteristics of a solar system; does one of those assumptions state that the collector must be an air-to-air type?

____

6. Solve the following problem concerning the procedure for collector sizing: As a rule of thumb, what is a quick way to size a collector for a domestic hot water system?

____

____

7. Select true statements concerning rules of thumb for solar refrigeration systems by placing an "X" in the appropriate blanks.

_____a. Since refrigeration systems affect cooling by removing water from the air as it comes in contact with a cold, refrigerated surface, conventional vapor-compressor cooling systems using electric motors are adaptable to systems using solar energy

_____b. Absorption systems are not adaptable to systems using solar energy

_____c. For economic reasons, the absorption systems appear to be the most usable in solar systems

_____d. Absorption systems currently available include:

1. Lithium-bromide-water units
2. Water-ammonia absorption units

_____e. Water-ammonia absorption units are more commercially available than other types of units

8. Complete the following list of statements concerning basic concepts of solar cooling with absorption systems.

a. Absorption systems are similar in principle to an ordinary, electrically operated vapor-compression ______________________________

b. Instead of a refrigerant like Freon in a conventional air conditioner, inorganic refrigerants, such as ______________, are used in an absorption machine together with an absorbent

c. An absorbent is a liquid which combines chemically with the ______________ and releases heat from the fluid mixture in the combination process

d. In a lithium-bromide-water unit, water is the refrigerant and the lithium-bromide is the ________________

e. In an ammonia-water unit, ammonia is the refrigerant and water is the absorbent

9. Match the types of lithium-bromide-water units on the right with their characteristics.

_____a. Cools air which contacts the cooling coils — 1. Water chiller

_____b. Cools water which contacts the cooling coils — 2. Air chiller

10. Select true statements concerning operating principles of an absorption air conditioner by placing an "X" in the appropriate blanks.

_____a. The cycle begins when water in the liquid mixture in the generator is boiled off and superheated with solar energy at a temperature between 170 and 210°F

_____b. The superheated water vapor passes from the generator to the condenser where it is cooled to about 100°F by the cooling water from an outdoor cooling tower

_____c. The vapor condenses to a liquid and is then revaporized through an expansion valve which cools the vapor-liquid mixture to a temperature of 100°F in the evaporator coils

_____d. The heat in the room air or water which is brought in contact with the evaporator is removed by the cooled refrigerant in the evaporator

_____e. The refrigerant then passes to the absorber where it recombines with the concentrated ammonia solution from the generator at a temperature of about 100°F

_____f. In this recombination process, refrigerant is released, and the water is removed by the cooling water from the cooling tower

_____g. The dilute solution of lithium-bromide and water in the absorber flows by gravity, or is pumped back to the generator, and the cycle is repeated

_____h. Some ammonia-water systems use a recouperator as a heat exchanger to make the system thermodynamically more efficient

11. Circle the words which best complete the following statements concerning system flow in a water chiller application.

a. The absorption chiller should be situated (away from, close to) the hot water storage tank to minimize heat loss from the pipelines connected to the tank

b. Hot water from the top of the storage tank is pumped through the (generator, condenser) by pump (P-2) and returned to the bottom of the tank; note that the piping connection goes through the auxiliary boiler

c. When the (water, temperature) in the storage tank is insufficient to operate the absorption chiller, the auxiliary boiler is used to provide heat to the generator

d. When the auxiliary boiler is used, the three-way valve at the bottom of the auxiliary boiler circulates the return water only through the auxiliary boiler so that auxiliary energy (is, is not) used to heat the solar storage tank

e. Pump size and head depend on the (flow, heat) rate and pressure loss through the system and also the size and length of piping

f. A wet cooling tower is needed with the absorption chiller to discharge the (water, heat) from the condenser and the absorber to the atmosphere

g. The (flow, size) of the cooling tower depends on the size of the absorption machine and the wet-bulb temperature of the ambient air

h. A pump (P-3) is needed to circulate the cooling water from the (tower, generator) through the absorber and condenser of the absorption machine

i. Chilled water from the evaporator is circulated to the fan-coil unit to cool the air in the (cooling tower, rooms)

12. Solve a problem concerning evaporative cooling with rock-bed storage: Would you recommend an evaporative cooling system with rock-bed storage for an application in Phoenix, Arizona, and why or why not?

____

____

13. Complete a sun-chart worksheet for a specific solar application.

14. Size a solar collector for a combination DHW and space heating solar system.

(NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

LOAD CALCULATIONS AND SOLAR COOLING
UNIT III

ANSWERS TO TEST

1. a. 17
   b. 5
   c. 6
   d. 10
   e. 4
   f. 12
   g. 3
   h. 14
   i. 19
   j. 16
   k. 18
   l. 1
   m. 15
   n. 8
   o. 9
   p. 11
   q. 2
   r. 7
   s. 13
   t. 20

2. Easier, because deep wells produce water at a relatively constant temperature

3. 18 degree days

4. Somebody has made a mistake in calculating the degree day adjustment factor because it can never be more than 1.0, so the adjustment factor will have to be calculated again

5. No

6. Size it so that it supplies 100% of the heat requirements for the month of May

7. c,d

8. a. Air conditioner
   b. Water and ammonia
   c. Refrigerant
   d. Absorbent

9. a. 2
   b. 1

10. a, b, d, g

11. a. Close to
    b. Generator
    c. Temperature
    d. Is not
    e. Flow
    f. Heat
    g. Size
    h. Tower
    i. Rooms

12. Yes, Phoenix is in a semi-arid region with cool night and low wet-bulb temperatures

13. Evaluated to the satisfaction of the instructor

14. Evaluated to the satisfaction of the instructor

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss features of passive solar design, how these features can be used to complement each other, and the characteristics of other passive solar concepts. The student should also be able to list the functions of components in a photovoltaic solar system, discuss basic rules for solar access planning, calculate shadow patterns, orient and landscape a model house and lot for maximum solar benefit, and build and operate a solar still. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to passive solar and other solar concepts with their correct definitions.
2. Select true statements concerning orientation for natural ventilation.
3. Solve a problem concerning the importance of wall-roof ratios.
4. Complete a list of statements concerning ways to use atriums in passive solar design.
5. Circle the words which best complete statements concerning the uses of earth berms in passive solar applications.
6. Complete a list of statements concerning entry locks and their uses in passive solar design.
7. Select true statements concerning greenhouses and their uses as entry locks in passive solar design.
8. Solve a problem concerning window shutters and their uses in passive solar design.
9. List six passive solar design features that function to complement each other.
10. Match other passive solar concepts with their characteristics.
11. Arrange in order the process for making photovoltaic solar cells.
12. State how a photovoltaic solar cell works.
13. Match components of a photovoltaic system with their functions.

14. Match terms concerning solar access with their definitions.

15. Complete a list of statements concerning solar azimuth and its use in solar access planning.

16. Select true statements concerning skyspace and its use in solar access planning.

17. Circle the words which best complete statements concerning rules of thumb for planning solar access.

18. Match basic levels of solar access with their requirements.

19. Select true statements concerning shadow patterns and their significance.

20. List three tree characteristics that must be considered in solar access planning.

21. Solve a problem concerning topography and its relation to solar skyspace.

22. Complete a list of statements concerning regulations and codes affecting solar applications.

23. Calculate the shadow pattern of a pole.

24. Demonstrate the ability to:

    a. Orient a model house and landscape a model lot for maximum solar benefit.

    b. Build and operate a solar still.

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment, and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Discuss and demonstrate the procedures outlined in the job sheets.

VII. Locate homes or businesses in your area that use passive solar concepts effectively, and plan a field trip to two or three of the installations; earth-sheltered homes, effective earth berms, and Thrombe walls provide good subjects.

VIII. Invite a local or area building inspector to discuss building codes and regulations that affect solar installations in your area.

IX. Have students investigate the status of solar access laws in your state and make reports in class; local state representatives or state senators can usually provide this information.

X. Visit a local greenhouse or invite the owner of a local greenhouse to talk to the class about the value of solar energy and how it affects to the economics of greenhouse operation.

XI. Assign groups of students to report on other energy and conservation devices, concepts, and techniques related to solar; such information is available from the Conservation and Renewable Energy Inquiry and Referral Service, P. O. Box 8900, Silver Springs, MD 20907; this organization also has a toll free telephone, 1-800-523-2929, to answer questions about energy and conservation; special reports might include:

  A. Wind energy

  B. Photovoltaic energy

  C. Bio-mass energy (wood and other nonfossil fuels)

  D. Solar ponds

  E. Hydro-electric energy

  F. Ocean thermal energy

XII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

  A. Objective sheet

  B. Information sheet

  C. Transparency masters

    1. TM 1--Passive Solar Design with Complementary Features

    2. TM 2--Photovoltaic System

    3. TM 3--Solar Skyspace Angles

  D. Assignment Sheet #1--Calculate the Shadow Pattern of a Pole

  E. Job sheets

    1. Job Sheet #1--Orient a Model House and Landscape a Model Lot for Maximum Solar Benefit

    2. Job Sheet #2--Build and Operate a Solar Still

  F. Test

  G. Answers to test

II. References:

  A. Logan, Joe D. *Solar Energy: Passive Systems.* St. Louis, MO: Milliken Publishing Co., 1980.

  B. The American Planning Association. *Protecting Solar Access for Residential Development: A Guidebook for Planning Officials.* Washington, D.C. 20402: U.S. Department of Housing and Urban Development and U.S. Department of Energy, 1979.

  C. *Solar Energy Project, General Solar Topics.* Washington, D.C. 20402: U.S. Department of Energy, 1979.

  D. *Solar Energy Project, Earth Science Activities.* Washington, D.C. 20402: U.S. Department of Energy, 1979.

  E. *Solar Energy Project, Text.* Washington, D.C. 20402: U.S. Department of Energy, 1979.

  F. Solar Energy Research Institute. *Photovoltaics Solar Electric Power Systems.* Washington, D.C. 20402: U.S. Department of Energy, 1980.

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

INFORMATION SHEET

I. Terms and definitions

A. Atrium--A hallway or small court usually used as an entry way

B. Earth berm--Earth placed around exterior walls to provide protection from extreme temperature changes, heavy winds, and air infiltration; may reach to window level, or, in the case of an earth-sheltered structure, it may cover three sides and even the roof

C. Earth contact--Structures that use ground mass temperature to help heat in winter and help cool in summer, and usually constructed with a berm that abuts but does not cover the house to leave space for window light and ventilation

D. Entry lock--An entrance-exit area constructed with two doors so arranged that when the outside door is opened, the second interior door is closed to prevent the infiltration of outside air into the interior of the structure, and the outside door is closed before the interior door is opened to further confine infiltration to a minimum

E. Natural orientation--The careful attention to site planning that physically places a home so it can best take advantage of local geographical, meteorological, and ecological patterns

(NOTE: This usually means south facing windows for maximum winter sunshine, and summer cooling with prevailing southwesterly winds, few or no windows facing prevailing winter winds from the northeast, and the advantageous use of deciduous trees to the south and west for summer shade and winter sunlight with evergreens north and east to shield against winter wind.)

F. Clerestory window--A vertical window placed in a wall or a roof; it permits a natural light supply to the interior; it is frequently placed above one's line of vision

G. Photovoltaics--The science of producing electrical current and voltage from sunlight through a conversion medium of silicon solar cells

H. Solid-to-void ratio--The relationship of solid materials to open spaces in a storage facility; usually expressed in percentages

Example: A storage facility with a 30 to 70% solid-to-void ratio means that 70% of the storage volume is occupied by solid materials and 30% of the storage volume is occupied by open or void spaces in which air can be stored or through which air can be moved

INFORMATION SHEET

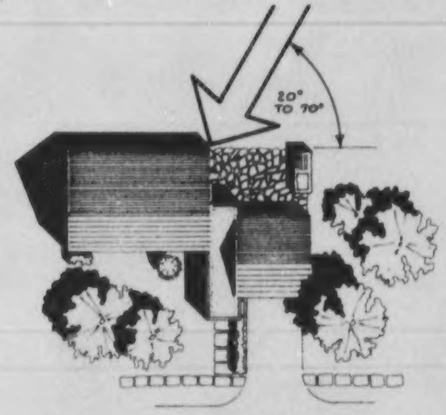
II. Orientation for natural ventilation

A. Prevailing summer breezes can be used to cool a home

B. The ideal orientation of the side of the house through which the breezes should enter is an oblique angle 20° to 70° between the wall and wind direction (Figure 1)

(NOTE: Your local weather bureau can give you the prevailing winds in your area, and a local airport has extensive knowledge concerning local wind patterns.)

FIGURE 1



Courtesy U.S. Department of Energy

C. Try to retain a south-facing orientation for large window areas

D. To protect facades from winter winds, locate evergreens, fences, and earth berms on the north side of the home

(NOTE: This orientation may vary to northeast or northwest depending on prevailing winter winds.)

E. On a south-facing hill, breezes tend to move up the hill during the day and down the hill at night

F. Near a body of water, breezes move from the water to the land during the day, and move in a reverse pattern at night

G. Natural ventilation and cooling can be increased by using casement-type windows or partially-opened shutters on the windward side of the house

(NOTE: Casement windows and shutters form projections which create mini-pressure zones in front of the window openings, and actually increase the velocity of the breeze passing into the openings.)

INFORMATION SHEET

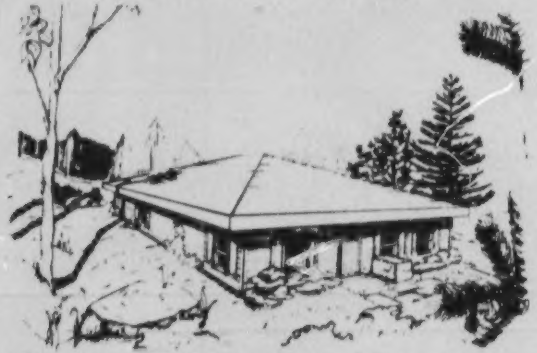
III. The importance of wall-roof ratios

A. During the winter months, a large amount of heat loss in a home occurs through exterior walls and particularly through and around windows and doors in those walls

B. A rectangular house configuration increases roof area and decreases wall area; this is advantageous because it is possible to include more insulation in the roof than in the walls

C. A rectangular house configuration also affords interior rooms with less exposure to the outside, and window area can be reduced, yet still provide major window exposure to the south (Figure 2)

FIGURE 2



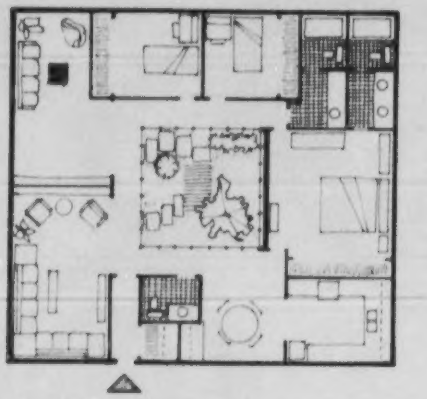
Courtesy U.S. Department of Energy

IV. Ways to use atriums in passive solar design

A. An atrium should be designed so that it is central to the other rooms in the home

B. Windows should be exposed to the inner atrium instead of to the outside to obtain a significant reduction in heat loss through windows and walls (Figure 3)

FIGURE 3



Courtesy U.S. Department of Energy

INFORMATION SHEET

C. Even if the atrium is unheated, the skylight will warm the atrium to a temperature higher than that outside in winter

D. Double or triple energy savings can be experienced if the atrium is used with insulated shutters as a passive solar collector

E. Heat gain in summer weather can be reduced if proper sun control and shading devices are used

V. The uses of earth berms in passive solar applications

A. Earth-berming and the introduction of below-grade living spaces requires careful attention to waterproofing, foundation drainage, insulation, exits and entrances, and humidity control

B. Earth-berming homes requires special attention to moisture proofing, rodents, insects, and even tree roots

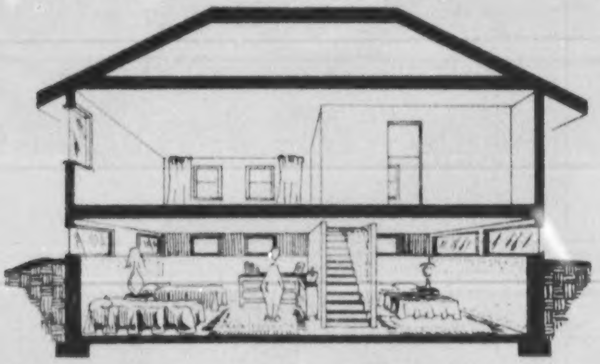
C. Earth is usually not a good insulator; its major benefit is its capability to moderate temperature change and provide protection from cold winter winds

(NOTE: The insulating properties of earth vary with locale and application, so the general rule stated above does have exceptions.)

D. From four to five feet below grade, earth has a relatively constant temperature of 55°F, and a duct with a small fan located in the berm can provide a simple passive cooling system

E. When bedrooms or other living areas are located below grade, the amount of excavation need not be increased, but the first floor is raised slightly to provide a minimum 7'-6" ceiling height; this height will accommodate 2' high clerestory windows and make the below grade living areas much more liveable (Figure 4)

FIGURE 4

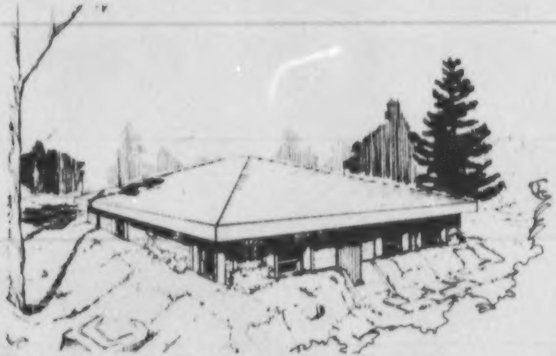


Courtesy U.S. Department of Energy

INFORMATION SHEET

F. When conventional windows are used, say with 3' high sills, earth can be bermed to the first floor sills (Figure 5)

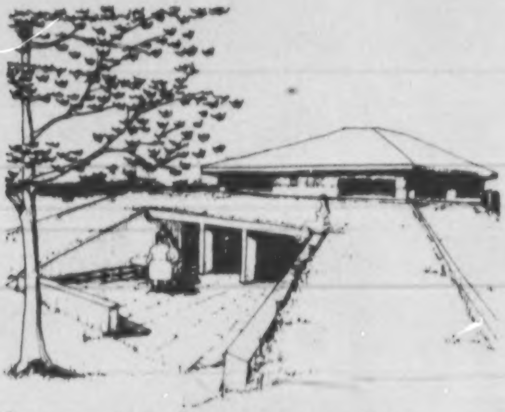
FIGURE 5



Courtesy U.S. Department of Energy

G. Maximum utilization of passive solar can be obtained with an earth berm that reaches to the roof eave; ventilation becomes an important concern in this design, and attention to ground water pressures and waterproofing are especially important (Figure 6)

FIGURE 6



Courtesy U.S. Department of Energy

VI. Entry locks and their uses in passive solar design

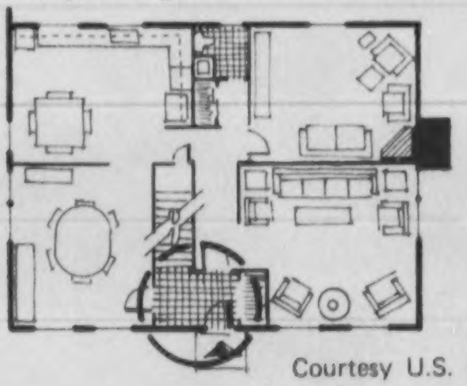
A. Large amounts of heated or cooled air may escape from a home each time a door is opened directly to the outside; entry locks decrease this heat loss and heat gain

B. An entry lock is designed to provide two doors, only one of which is normally open at any moment, separated by a small unheated or uncooled air space

INFORMATION SHEET

C. An entry lock may be designed into the interior of the house (Figure 7)

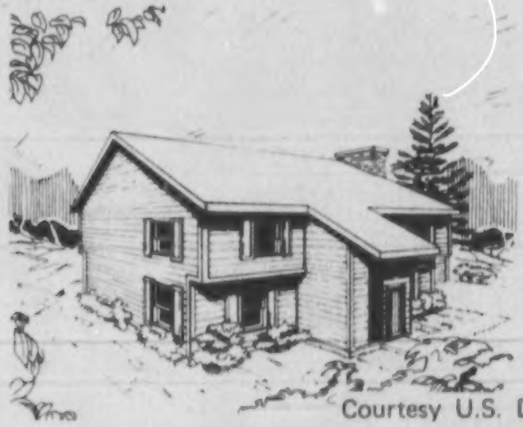
FIGURE 7



Courtesy U.S. Department of Energy

D. An entry lock may be designed onto the exterior of the house or added to an existing house (Figure 8)

FIGURE 8



Courtesy U.S. Department of Energy

VII. Greenhouses and their uses as entry locks in passive solar design (Figure 9)

A. An entry lock designed as a greenhouse takes advantage of radiation through large glass areas to keep temperatures at reasonable levels, even without supplementary heating, in winter

B. By adding plants and other insulating and shading devices, an entry lock greenhouse can moderate heat gain in summer

C. An entry lock greenhouse increases the thermal resistance of the outside envelope of a house by

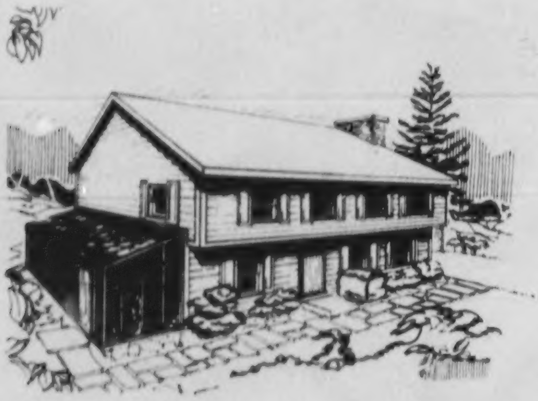
1. Increasing the outside temperature of the main exterior wall in cold weather and decreasing it in warm weather

2. Reducing infiltration losses around doors and windows

INFORMATION SHEET

D. When so designed, an entry lock greenhouse can be utilized year round for growing vegetables and other plants

FIGURE 9

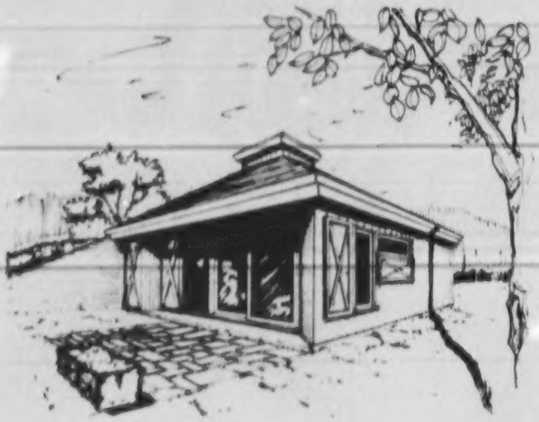


Courtesy U.S. Department of Energy

VIII. Window shutters and their use in passive solar design (Figure 10)

A. Shutters must have genuine insulating value; the best shutter is one with a wood face and an insulating core

FIGURE 10



Courtesy U.S. Department of Energy

INFORMATION SHEET

B. Shutters should be opened in relation to sun movement (Figure 11)

FIGURE 11

Location of Shutters	Winter Opening Time	Summer Opening Time
East wall	8 a.m.-11 a.m.	1 p.m.-4 p.m.
South wall	8 a.m.-4 p.m.	7-9 a.m.; 3-5 p.m.
West wall	1 p.m.-4 p.m.	8 a.m.-11 a.m.
North wall	Any 3 daylight hours	8 a.m.-7 p.m.

IX. Passive design features that function to complement each other (Transparency 1)

A. One-story rectangular configuration

B. Minimum perimeter distance

C. Window shutters

D. Atrium and entry locks

E. Earth berming

F. Maximum insulation in roof and walls

G. Weatherstripping and storm windows

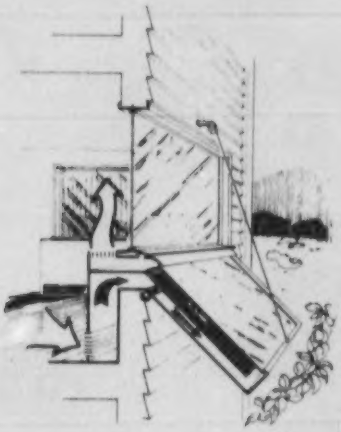
(NOTE: These features have been tested in a test situation in New York state and, in combination, have reduced heat loss by more than 30%, reduced heat gain by more than 20%, and reduced hot water costs by more than 35%.)

INFORMATION SHEET

X. Other passive solar concepts and their characteristics

A. Solar window shutter--This hinged shutter can be inclined to the appropriate radiation angle; it retains solar radiation and has operable vents to facilitate heat transfer into the room when the shutter is closed (Figure 12)

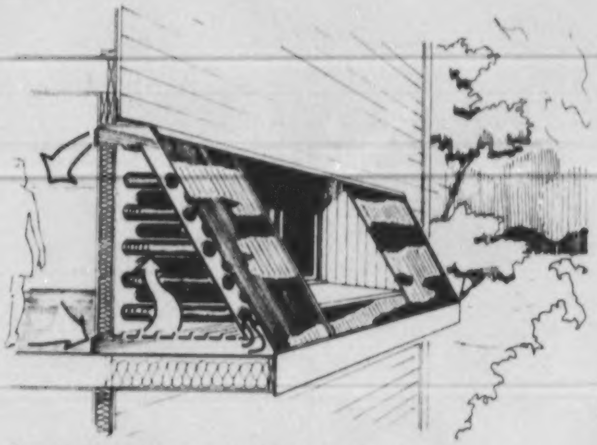
FIGURE 12



Courtesy U.S. Department of Energy

B. Solar window unit--This collector incorporates collection, storage, and direct venting into the room; would probably have to be used in a southeast room (Figure 13)

FIGURE 13

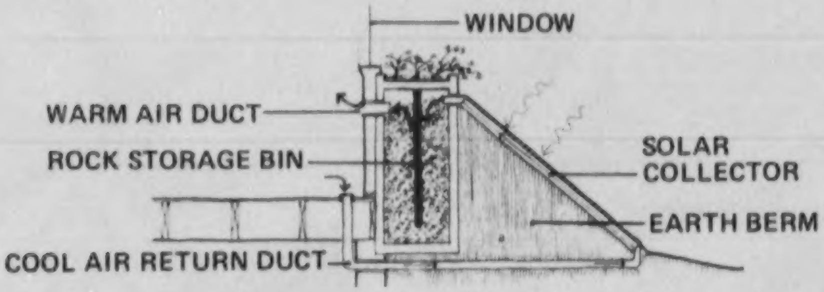


Courtesy U.S. Department of Energy

INFORMATION SHEET

C. Solar collectors on earth berms--The berm angle should be the same as the average solar radiation angle for the locale; unit is self-contained and heat is transferred into the home by convection and by manually-operated vents (Figure 14)

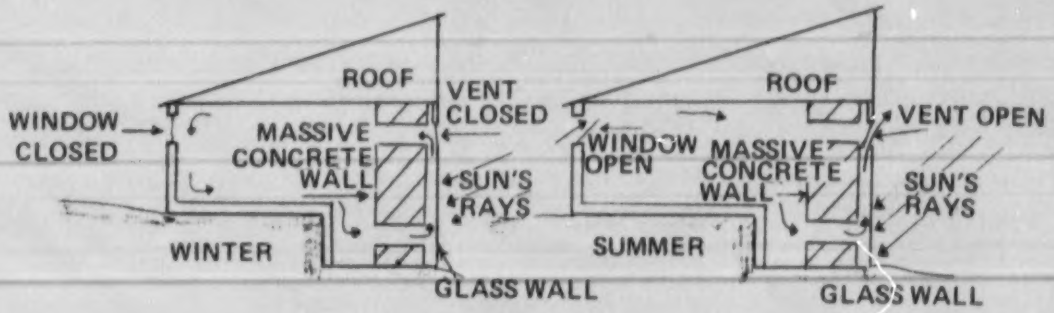
FIGURE 14


WINDOW
WARM AIR DUCT
ROCK STORAGE BIN
SOLAR COLLECTOR
EARTH BERM
COOL AIR RETURN DUCT

Courtesy U.S. Department of Energy

D. Thrombe wall--A thick wall, usually of concrete or brick, that functions as a natural collector and storage area combined and takes advantage of the convection tendencies of heated air to circulate warmed air through a space (Figure 15)

FIGURE 15


WINDOW CLOSED
ROOF
VENT CLOSED
MASSIVE CONCRETE WALL
SUN'S RAYS
WINTER
GLASS WALL
ROOF
VENT OPEN
WINDOW OPEN
MASSIVE CONCRETE WALL
SUN'S RAYS
SUMMER
GLASS WALL

Courtesy U.S. Department of Energy

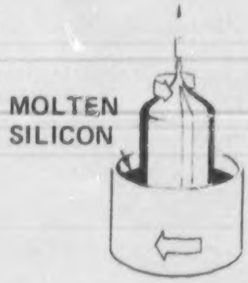
INFORMATION SHEET

XI. The process for making photovoltaic solar cells

A. Silicon crystals obtained from sand go through an extensive purification process

B. Silicon crystals are grown in cylindrical ingots from purified molten silicon (Figure 16)

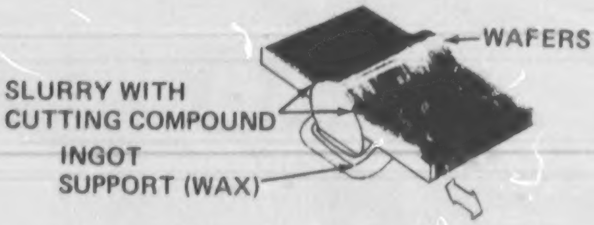
FIGURE 16


MOLTEN
SILICON

Courtesy Solar Energy Research Institute

C. The cylindrical ingots are then sliced into wafers (Figure 17)

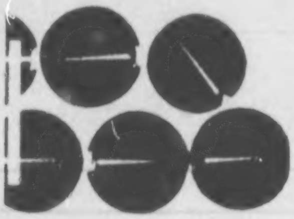
FIGURE 17


WAFERS
SLURRY WITH
CUTTING COMPOUND
INGOT
SUPPORT (WAX)

Courtesy Solar Energy Research Institute

D. The wafers are then connected and formed into easy to handle modules (Figure 18)

FIGURE 18



Courtesy Solar Energy Research Institute

INFORMATION SHEET

XII. How a photovoltaic solar cell works

A. When sunlight strikes the solar cell, internal electrons are energized and electricity is generated

B. Useful electricity is drawn off through wires attached to the cell

XIII. Components of a photovoltaic system and their functions (Transparency 2)

A. Solar cells--Supply a fixed current through interconnections between modules or arrays of modules

B. Storage batteries--Act as buffers between the solar cell array and the load, the device using electricity; supplies power to the load during periods of insufficient sunlight and recharged during periods of high sunlight

C. Blocking diode--That part of the power conditioning equipment which prevents battery current from draining back into the array at night when the system is not producing power

D. Voltage regulator--That part of the power conditioning equipment which prevents the batteries from overcharging, a condition which shortens battery life

E. Inverters--That part of the power conditioning equipment which changes the direct current produced by the photovoltaic array into alternating current

F. Storage/backup system--An arrangement in a larger photovoltaic application whereby a local utility purchases excess electricity produced by the system during sunny days, and supplies the user with electricity during cloudy days or at night when the system requires more electricity than it can produce

XIV. Terms concerning solar access and their definitions

A. Solar skyspace--That portion of the sky a collector must "see" to perform effectively

B. Solar time--Time expressed in relation to the position of the sun in the sky

C. Solar noon--The time at which the sun is at its highest point in the sky

(NOTE: Local time is often different from solar time; in other words, at solar noon the sun is at its highest point, but this time might not correspond with noon local time.)

D. Winter solstice--December 21; the time when the sun is at its lowest altitude in the sky and shadows are the longest

E. Summer solstice--Usually June 21; the time when the sun is at its highest altitude in the sky and shadows are the shortest

INFORMATION SHEET

XV. Solar azimuth and its use in solar access planning

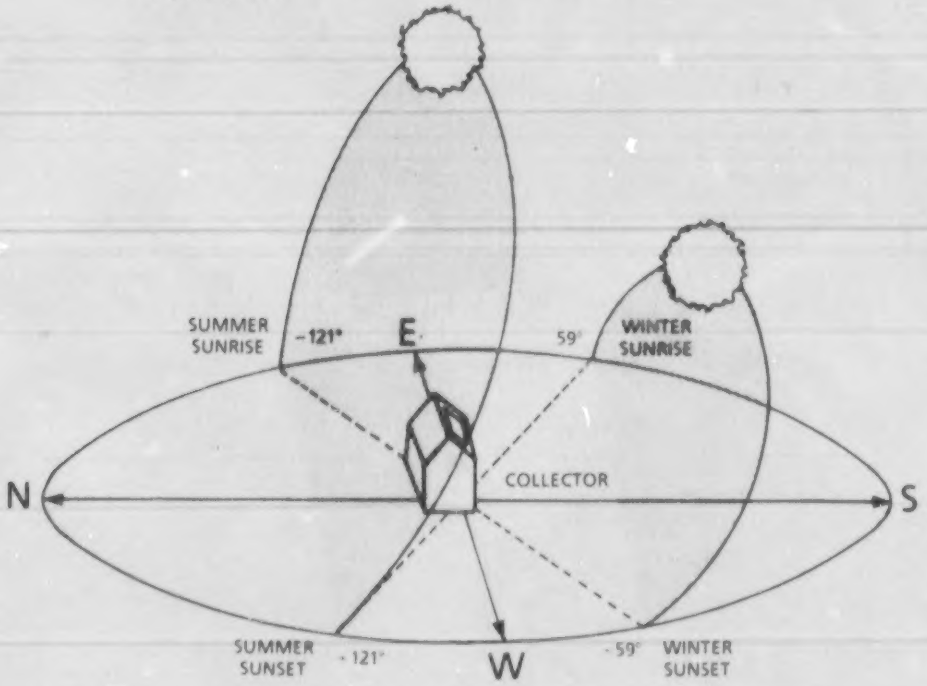
A. Solar azimuth is measured from true south, with a negative value to the east and positive value to the west

(NOTE: Do not confuse solar azimuth with true or magnetic north which is what azimuth means when used in a navigational sense.)

B. Since solar access planning involves protecting solar collectors from obstructions lying to the south of the collectors, the concept of a true south solar azimuth makes it easier to determine skyspace and analyze shading and the casting of shadows (Figure 19)

Example: At 40 degrees north latitude on December 21, the altitude of the sun at sunrise is a large negative one, 59 degrees to the east of south, or a conventional azimuth of 121 degrees; the azimuth increases until it reaches the same positive azimuth as its negative rising azimuth, +59 degrees west of south, or a conventional azimuth of 239 degrees; in summer, the solar azimuth increases to a -121° at summer sunrise and a +121° at summer sunset

FIGURE 19



Courtesy U.S. Department of Energy

INFORMATION SHEET

XVI. Skyspace and its use in solar access planning

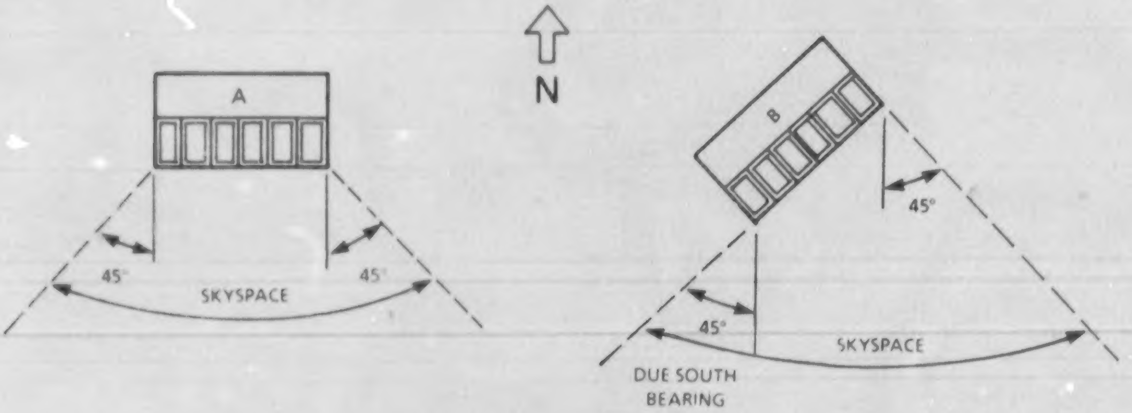
A. The angles of solar altitude and solar azimuth define skyspace, and it is skyspace that must be protected from shading by trees, buildings, or other obstructions

B. The altitude of the sun on December 21 and June 21 determines the upper and lower boundaries of needed skyspace

C. 45 degree solar skyspace azimuths are suitable for latitudes up to 40 degrees north (Figure 20)

FIGURE 20

Solar Skyspace (Plan View)



Courtesy U.S. Department of Energy

D. At latitudes beyond 40 degrees north, solar skyspace azimuths should be 50 degrees for both a.m. and p.m. angles (Transparency 3)

XVII. Rules of thumb for planning solar access

A. In most cases, it is the lowest altitude of the sun reached on December 21 that is most important for protecting solar access

B. On December 21, shadows are the longest, and it is usually safe to assume that if longer shadows do not shade a collector, then shorter shadows will not shade it, either

C. It is not necessary that solar collectors be guaranteed access to the sun from sunrise to sunset because solar altitudes below 12 degrees are essentially useless for solar energy collection purposes

D. It is almost impossible to maintain complete open space from horizon to horizon around a solar collector

INFORMATION SHEET

E. The solar skyspace that must be protected is also dependent on the nature of the solar energy system being used, and the time of day and season of the year in which it is to be used (Figure 21)

FIGURE 21

Skyspace and Solar Energy Use Table

Use	Skyspace
Hot Water Heating	Year-round—use lowest winter and highest summer altitude to determine skyspace
Space Heating	Heating season only—use lowest winter and medium spring/fall altitude to determine skyspace
Air Conditioning	Cooling season only—use medium spring/fall and highest summer altitude to determine skyspace

Courtesy U.S. Department of Energy

XVIII. Basic levels of solar access and their requirements (Figure 22)

A. Rooftop protection--Protects the sunlight falling on south-facing rooftops of new dwellings and apartments constructed in a community

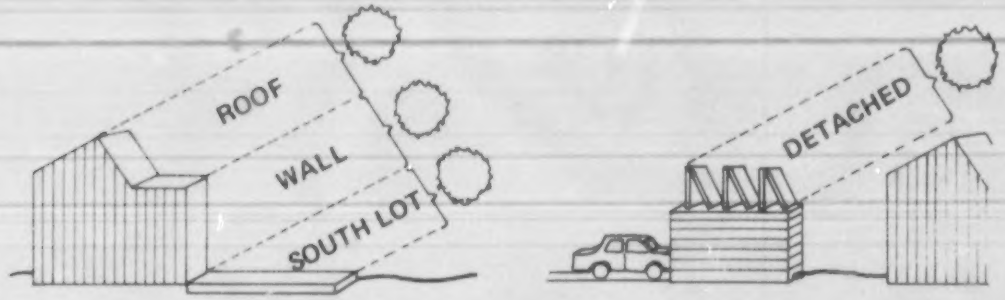
B. South wall protection--Protects south walls of new construction

C. South lot protection--Protects part of a lot adjacent to a south-facing wall

INFORMATION SHEET

D. Detached collector protection--Protects part of a lot for use by detached solar systems

FIGURE 22



Courtesy U.S. Department of Energy

XIX. Shadow patterns and their significance

A. A shadow pattern is the composite shape of a shadow cast by an object over fixed solar azimuths

B. A shadow pattern represents every spot shaded by an object during an entire time period, although only a small portion of shadow pattern will be shaded at any given time

C. Winter shadow patterns are most valuable because they represent the worst-possible-case, and when solar access is protected in winter, it is usually protected in summer

D. Shadow pattern data, whether collected by aerial photographs or taken in a car with a "windshield survey," should be taken at least three times; morning, noon, and afternoon on December 21

E. Shadow patterns may be calculated by formula or by using shadow length tables

(NOTE: A sample procedure for calculating shadow patterns follows in Assignment Sheet #1.)

XX. Tree characteristics that must be considered in solar access planning

A. Mature height of trees of a species

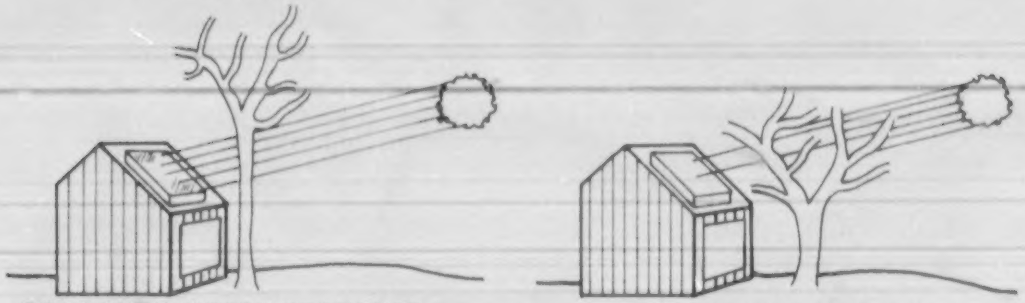
B. Mature diameter of the tree crown

C. Seasonal variations in foliage, taking into account the distinction between deciduous species, most of which shed leaves in autumn, and evergreen or conifers which mostly do not shed leaves

INFORMATION SHEET

D. The distance from the ground to the crown (Figure 23)

FIGURE 23



SUN SHINES UNDER BRANCHES – MORE RADIATION REACHES COLLECTOR

SUN SHINES THROUGH BRANCHES – LESS RADIATION REACHES COLLECTOR

Courtesy U.S. Department of Energy

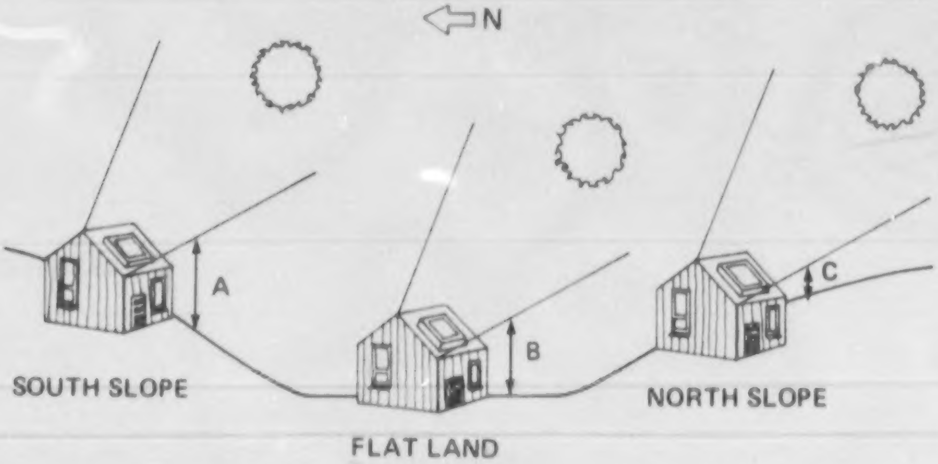
XXI. Topography and its relation to solar skyspace

A. Changes in topography do not change solar skyspace, but it can change the distance between the ground and the lower edge of the skyspace

B. A south slope automatically aims its collector higher, so neighboring objects can be higher without casting shadows on it

C. A collector on a north slope will be aimed toward the crest of a hill, so even very short objects may cast shadows on the collector (Figure 24)

FIGURE 24



DISTANCE A IS GREATER THAN B. AND B IS GREATER THAN C.

Courtesy U.S. Department of Energy

INFORMATION SHEET

XXII. Regulations and codes affecting solar applications

A. Solar access laws--Laws passed by state or local governments; these laws restrict the building of structures that would block neighboring sites from access to the rays of sunlight

B. Solar easements--State or local laws which set specific space requirements for solar access in much the same manner that easements are set aside for utilities

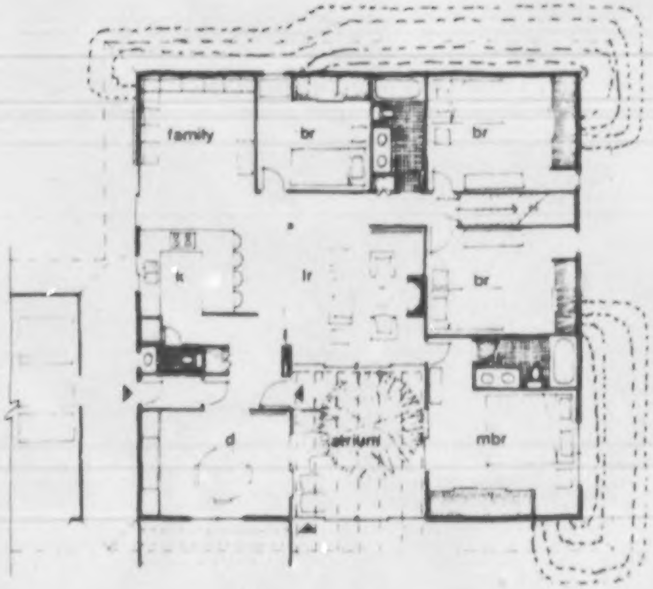
(NOTE: A model ordinance for solar access laws and solar easements is available from HUD User, P. O. Box 280, Germantown, MD 20767.)

C. State and local building codes--Codes setting up standards for plumbing, electrical, mechanical, and general structural component quality of structural materials; some codes have been modified to expressly treat solar applications and others have not; it is always best to check local codes, in particular, before starting a solar application

D. Guidelines for solar collector installation on roofs--Since solar systems require maintenance, considerations must be given to the placement of collectors; rooftop traffic pads have to be installed so maintenance personnel can walk around the collectors, collectors must be a safe distance from the edge of the roof, and installation procedures should respect the integrity of the roof

(NOTE: These guidelines were prepared by the National Bureau of Standards and are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.)

Passive Solar Design with Complementary Features


family
br
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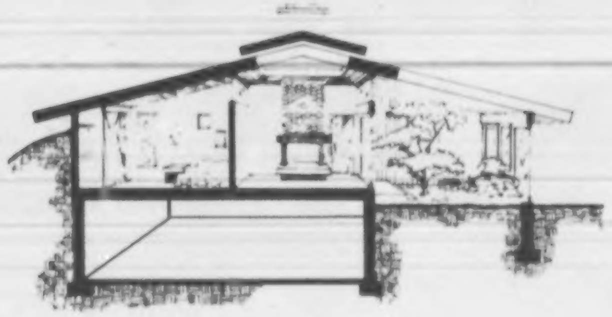
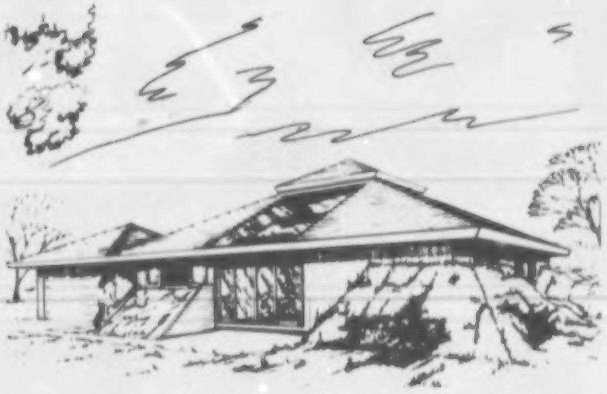
atrium
mbr

Floor Plan



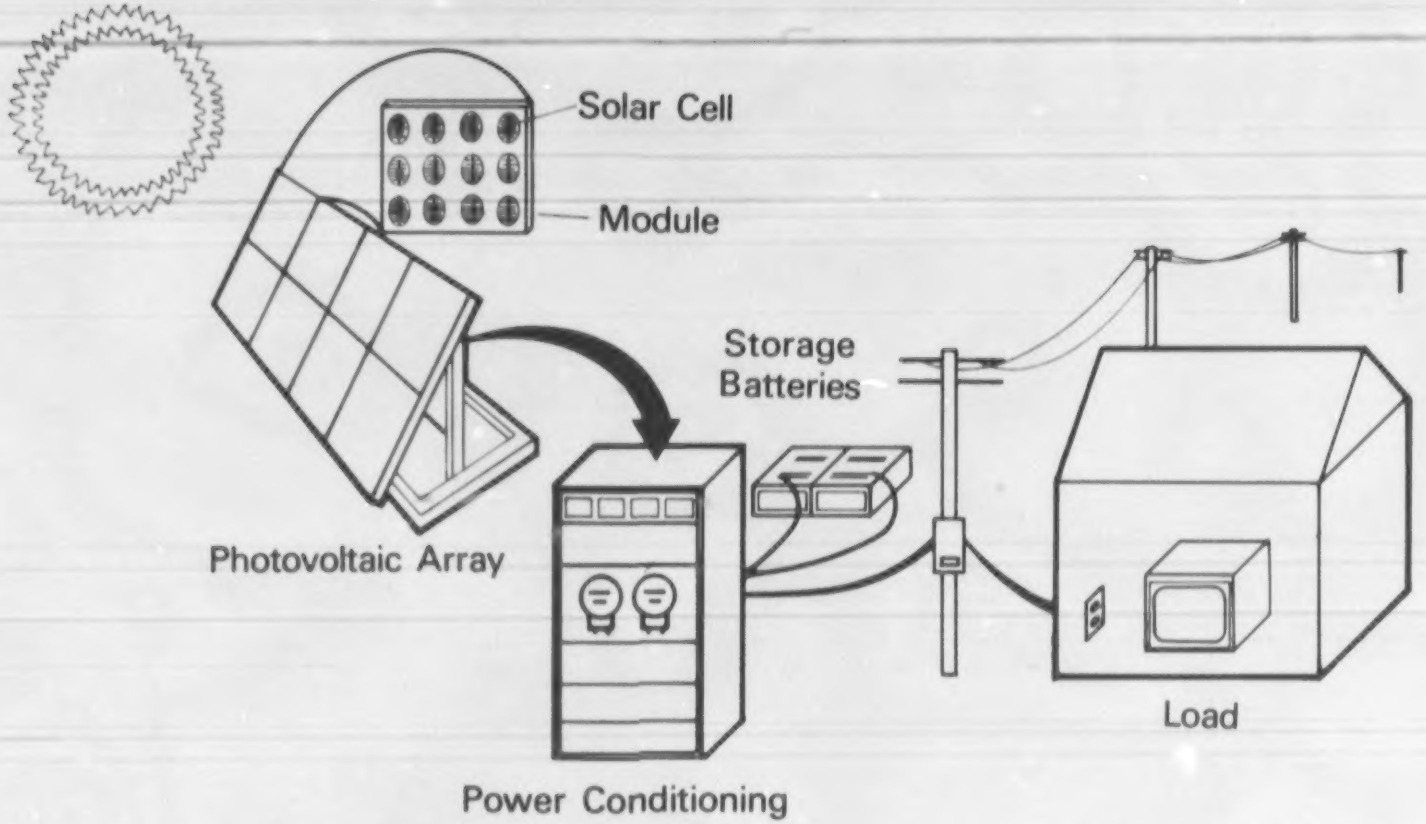
Section



Perspective

Courtesy U.S. Department of Energy

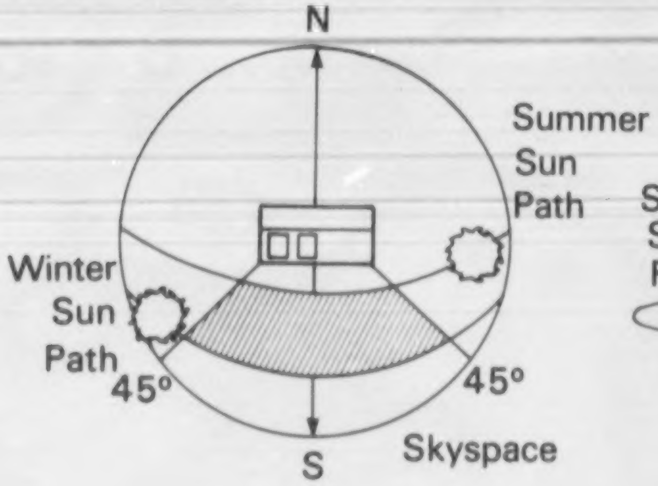
Photovoltaic System


Solar Cell
Module
Storage Batteries
Photovoltaic Array
Load
Power Conditioning

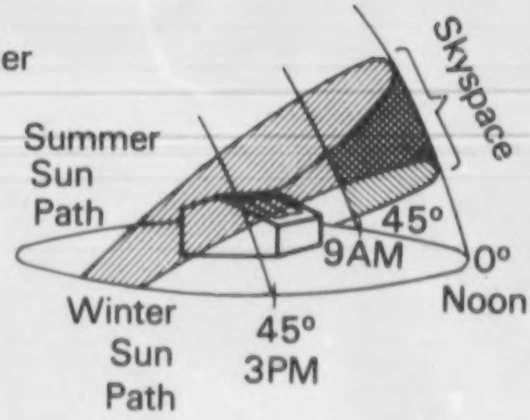
Courtesy U.S. Department of Energy

Solar Skyspace Angles

Solar Skyspace (Plan View)



Solar Skyspace (Isometric View)



Recommended Skyspace Angles for December 21st

	AM/PM Position*			Percent
Latitude	Azimuth	Altitude	Noon Altitude	Radiation***
25°	45°	25°	42°	76%
30°	45°	20°	37°	80%
35°	45°	16°	32°	85%
40°	45°	12°	27°	90%
45°***	(50°)	(12°)	22°	88%
48°***	(50°)	(12°)	18°	87%

The AM/PM angles presented in this chart are the same for both east of south and west of south. For example, if the skyspace azimuth is 50°, then the protected area goes from 50° east of south to 50° west of south.

**The 50° azimuths are not based on December 21st, but are suggested as a compromise to assure solar access during the entire heating season exclusive of the winter solstice period. Similarly, the 12 degree altitudes apply only to those months when the sun's path is 12 degrees above the horizon within the 50 degree azimuth angles.

***Radiation is based on the percentage of total available radiation falling on a horizontal surface on December 21. Example: If the skyspace between 45° east of south and 45° west of south is protected at 30° latitude, then 80% of the available radiation will strike the collector. If the collector is tilted, then these percentages may be even higher.

Courtesy U.S. Department of Energy

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

ASSIGNMENT SHEET #1--CALCULATE THE SHADOW PATTERN OF A POLE

Directions: Use the shadow length table and the procedure in the following example to calculate and diagram shadow patterns of a pole.

DATA: Pole is 30 feet high, location is 40° north latitude, and the pole is on land that slopes to the southeast at a 10% grade; all data is for December 21

Shadow Length Table for 40° North Latitude

LATITUDE 40°

	N			NE			E			SE			S		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8
5%	5.7	2.2	5.7	4.8	2.2	6.2	4.1	2.0	5.7	3.8	1.9	4.8	4.1	1.8	4.1
10%	7.2	2.5	7.2	4.8	2.3	9.1	3.6	2.0	7.2	3.2	1.8	4.8	3.6	1.7	3.6
15%	9.6	2.9	9.6	4.8	2.6	16.6	3.2	2.0	9.1	2.8	1.7	4.8	3.2	1.6	3.2
20%	14.5	3.4	14.5	4.8	2.8	97 5	2.8	2.0	14.5	2.4	1.6	4.8	2.8	1.5	2.8

STEP 1: From the above table, find the shadow length values for a.m., noon, and p.m.

STEP 2: Read the intersection of the columns labeled "SE" and "10%" as indicated on the shadow length table

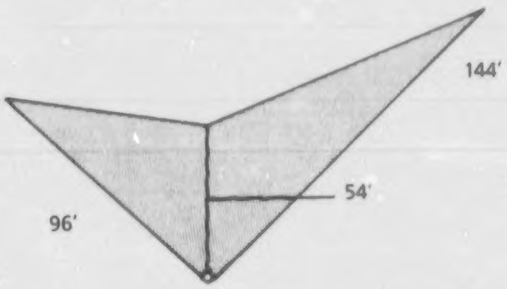
STEP 3: Multiply all values by, in this case, 30, because the values given in the table are for a one-foot pole

a.m. value	x	pole height	=	a.m. shadow length
3.2		30		96 feet
noon value	x	pole height	=	noon length
1.8		30		54 feet
p.m. value	x	pole height	=	p.m. length
4.8		30		144 feet

ASSIGNMENT SHEET #1

STEP 4: Scale the shadow lengths out on paper as viewed from overhead and connect the end points as shown in Figure 1

FIGURE 1 Shadow of pole on Dec. 21 at 40° Latitude on a 10% S.E. Slope



45° boundaries of skyspace are used to define area of shadow that will block important sunlight.

Courtesy U.S. Department of Energy

STEP 5: Your instructor will provide you with the height of three poles in the vicinity of your classroom, and may assign actual or imagined grades to the land they are on; assume a latitude of 40° north, calculate the a.m., noon, and p.m. shadow lengths as shown in STEP 3, and scale the shadow patterns to form diagrams as shown in STEP 4

(NOTE: Use graph paper the same size as that used by other students so that your scale diagrams can be compared with those of other students when the activity is completed.)

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

JOB SHEET #1--ORIENT A MODEL HOUSE AND LANDSCAPE A MODEL LOT FOR MAXIMUM SOLAR BENEFIT

I. Tools and materials

A. Scissors

B. Tape

C. Straightedge

D. Worksheets A, B, and C

E. Lamp for light source

II. Procedure

A. Cut and fold the model house in Worksheet A, and assemble it without taping

B. Place the folded model house on the model plot plan in Worksheet B

C. Determine the best location for room, window, and door placements

D. Unfold the model house and draw in the windows and doors

E. Refold the model house and tape it together

F. Tape the roof in place

G. Place the taped model house on the plot plan

H. Cut out the model trees and shrubs in Worksheet C and fold the bases

I. Tape toothpicks to the back of tree models to give them added strength

J. Use as many tree models as you feel are necessary for the site, and tape all additional models into place as they should be in summer weather

(NOTE: Remember that most deciduous trees lose their leaves in autumn.)

K. Set the light source from the lamp at the approximate angles the sun would have in summer

L. Check the effectiveness of summer shading on your model

M. Remove the deciduous summer trees and replace them with deciduous winter tree models

JOB SHEET #1

N. Set the light source from the lamp at the approximate angles the sun would have in winter

O. Check the effectiveness of available sunlight for your winter model

P. Answer the following questions:

1. How does your model house compare to those of other students in placement of windows and doors?

   ____

2. In which direction should the largest roof overhang face to take advantage of winter sun while avoiding summer sun?

   ____

3. If an earth berm were recommended for your model house, where would you place it?

   ____

4. If your model lot were on a south-facing hill, would that affect the orientation you selected?

   ____

5. Explain your answer to question 4. ______________________________

   ____

6. If your model home site had a lake one-quarter mile due west, would that affect the orientation you selected?

   ____

7. Explain your answer to question 6. ______________________________

   ____

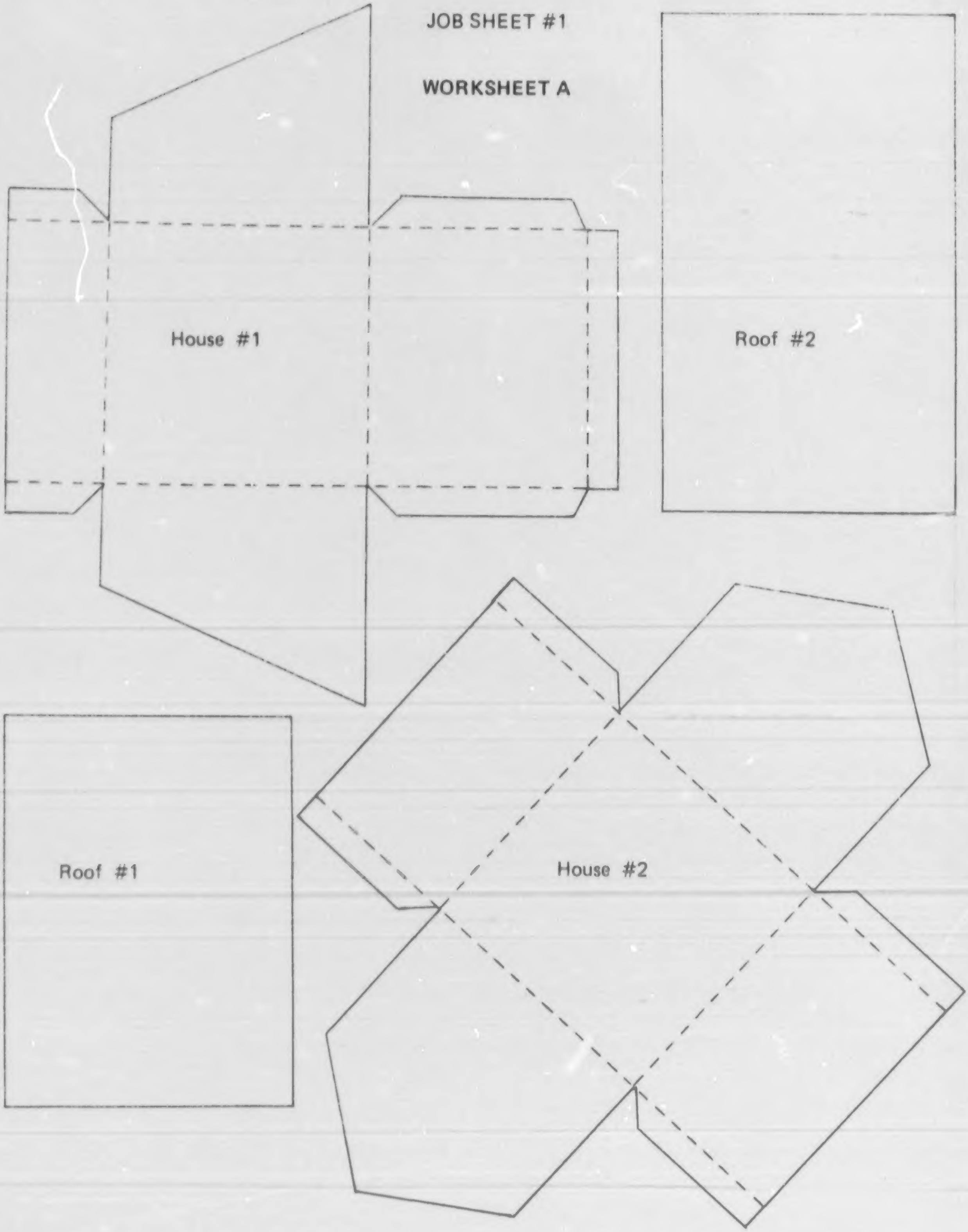
8. What kind of windows and window arrangements would you recommend for your model home?

   ____

   ____

JOB SHEET #1

WORKSHEET A


House #1
Roof #2
Roof #1
House #2

JOB SHEET #1

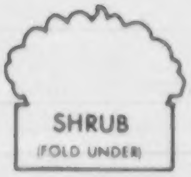
WORKSHEET B

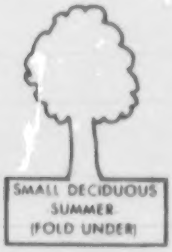
KEY

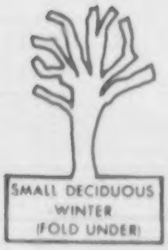
—o—o—o—o—	Fence (Indicate Height)
═	Driveway
═	Sidewalk

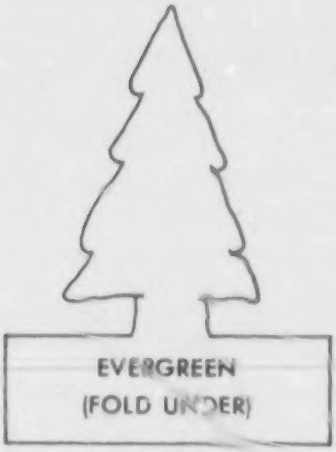
JOB SHEET #1

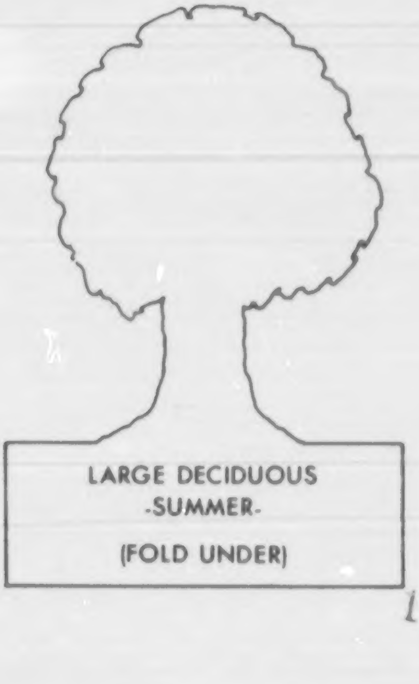
WORKSHEET C

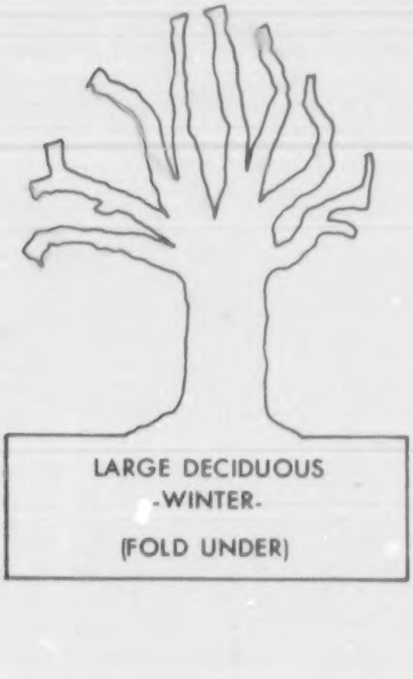

SHRUB
(FOLD UNDER)


SMALL DECIDUOUS
-SUMMER-
(FOLD UNDER)


SMALL DECIDUOUS
-WINTER-
(FOLD UNDER)


EVERGREEN
(FOLD UNDER)


LARGE DECIDUOUS
-SUMMER-
(FOLD UNDER)


LARGE DECIDUOUS
-WINTER-
(FOLD UNDER)

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

JOB SHEET #2--BUILD AND OPERATE A SOLAR STILL

I. Tools and materials

A. Strong, flexible, transparent plastic sheet at least 1m (39-inches) square

(NOTE: Plastic storm window covering will do.)

B. Several fist-size rocks

C. Shovel

D. Two thermometers

E. Wristwatch or stopwatch

F. Piece of cardboard large enough to cover half a thermometer

G. Graph paper

H. Collecting vessel or graduated cylinder

I. Cobalt chloride test paper (optional)

J. Protractor

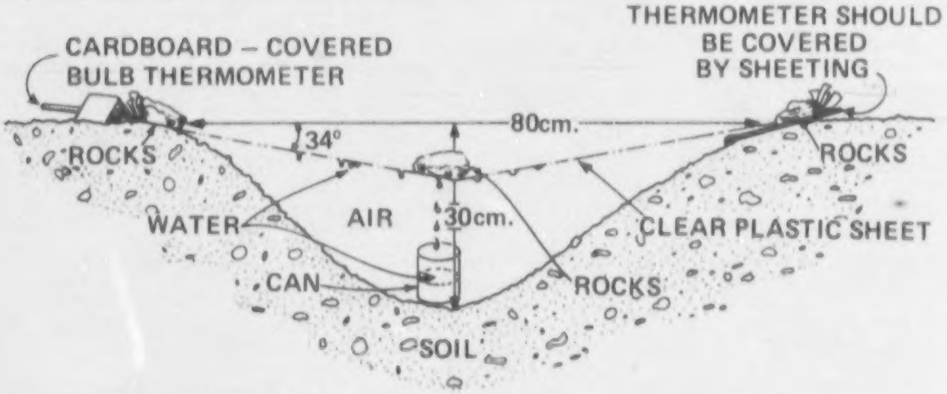
II. Procedure

A. Dig a hole about 80cm (32") in diameter and 30cm (12") deep, and place the soil to one side

JOB SHEET #2

B. Center the graduated cylinder or collecting vessel in the bottom of the hole (Figure 1)

FIGURE 1


CARDBOARD – COVERED BULB THERMOMETER
THERMOMETER SHOULD BE COVERED BY SHEETING
80cm.
34°
ROCKS
ROCKS
WATER
AIR
30cm.
CLEAR PLASTIC SHEET
CAN
ROCKS
SOIL

Courtesy U.S. Department of Energy

C. Place the plastic sheet over the hole and firmly anchor one edge with small rocks

D. Place one small rock in the center of the plastic sheet directly over the collecting vessel, while allowing the plastic sheet to stretch to at least a 34° angle from the horizon

(NOTE: Have another student help with this step; one should manage the weighted plastic sheet while the other uses the protractor to properly attain the right angle.)

E. Seal the other edge of the plastic sheet with soil and small rocks

F. Insert one thermometer under the plastic sheet with the bulb extending into the air chamber beneath the plastic sheet

(NOTE: Be sure to position the thermometer so the scale can be read.)

G. Place the other thermometer at the other edge of the sheet, cover the half of the thermometer with the bulb on it with cardboard, and position the thermometer so the scale can be read

H. Simultaneously record the temperatures of both the inside and the outside thermometers at two-minute intervals

JOB SHEET #2

I. Enter your readings in the following data table:

Reading #	Inside Thermometer	Outside Thermometer
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

J. Remove the plastic sheet after 20 minutes have passed

K. Retrieve the collecting vessel

L. Pour the contents of the collecting vessel into a graduated cylinder and record the amount of liquid collected in milliliters (ml)

M. Check the liquid collected to determine its identity

(NOTE: Cobalt chloride paper may be used for this test, but chances are you can identify the liquid with no great difficulty.)

N. Fill in the hole and return the shovel and other equipment to a proper storage area

O. Answer the following questions:

1. Where did the water come from?________________________________
2. Why did the water collect on the underside of the plastic sheet?

   ____
3. Why did the water drip into the collecting vessel?________________

   ____

JOB SHEET #2

4. How did solar energy cause the still to operate?____________________

____

5. If you were stranded in the desert with no water, and had the proper equipment in your survival gear, what would you do?

____

6. What do the readings in your data table reflect concerning the operation of a solar still?

____

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

NAME ______________________________

TEST

1. Match the terms on the right with their correct definitions.

______a. A hallway or small court usually used as an entry way

______b. Earth placed around exterior walls to provide protection from extreme temperature changes, heavy winds, and air infiltration; may reach to window level, or, in the case of an earth-sheltered structure, it may cover three sides and even the roof

______c. Structures that use ground mass temperature to help heat in winter and help cool in summer, and usually constructed with a berm that abuts but does not cover the house to leave space for window light and ventilation

______d. An entrance-exit area constructed with two doors so arranged that when the outside door is opened, the second interior door is closed to prevent the infiltration of outside air into the interior of the structure, and the outside door is closed before the interior door is opened to further confine infiltration to a minimum

______e. The careful attention to site planning that physically places a home so it can best take advantage of local geographical, meteorological, and ecological patterns

______f. A vertical window placed in a wall or a roof; it permits a natural light supply to the interior; it is frequently placed above one's line of vision

______g. The science of producing electrical current and voltage from sunlight through a conversion medium of silicon solar cells

______h. The relationship of solid materials to open spaces in a storage facility; usually expressed in percentages

1. Entry lock
2. Atrium
3. Photovoltaics
4. Natural Orientation
5. Earth berm
6. Clerestory window
7. Earth contact
8. Solid-to-void ratio

2. Select true statements concerning orientation for natural ventilation by placing an "X" in the appropriate blanks.

______a. Prevailing summer breezes can be used to cool a home

______b. The ideal orientation of the side of the house through which the breezes should enter is a right angle 20° to 90° between the wall and wind direction

______c. Try to retain a north facing orientation for large window areas

______d. To protect facades from winter winds, locate evergreens, fences, and earth berms on the north side of the home

______e. On a south-facing hill, breezes tend to move up the hill during the day and down the hill at night

______f. Near a body of water, breezes move from the land to the water during the day, and move in a reverse pattern at night

______g. Natural ventilation and cooling can be increased by using casement-type windows or partially-opened shutters on the windward side of the house

3. Solve the following problem concerning the importance of wall-roof ratios: A rectangular house configuration increases roof area and decreases wall area; it also provides interior rooms with less exposure to the outside; what are the advantages offered by these two conditions?

____

____

4. Complete the following list of statements concerning ways to use atriums in passive solar design.

a. An atrium should be designed so that it is ________________ to the other rooms in the home

b. ________________ should be exposed to the inner atrium instead of to the outside to obtain a significant reduction in heat loss through windows and walls

c. Even if the atrium is unheated, the ________________ will warm the atrium to a temperature higher than that outside in winter

d. Double or triple energy savings can be experienced if the atrium is used with ______________________ as a passive solar collector

e. ________________ in summer weather can be reduced if proper sun control and shading devices are used

5. Circle the words which best complete the following statements concerning the uses of earth berms in passive solar applications.

   a. Earth-berming and the introduction of below-grade living spaces requires careful attention to waterproofing, foundation drainage, insulation, exits and entrances, and (temperature, humidity)

   b. Earth-berming homes requires special attention to moisture proofing, rodents, insects, and even (temperature change, tree roots)

   c. Earth is usually not a good insulator; its major benefit is its capability to moderate temperature change and provide protection from (tornadoes, cold winter winds)

   d. From four to five feet below grade, earth has a relatively constant temperature of (65°F, 55°F), and a duct with a small fan located in the berm can provide a simple passive cooling system

   e. When bedrooms or other living areas are located (above, below) grade, the amount of excavation need not be increased, but the first floor is raised slightly to provide a minimum 7'-6" ceiling height; this height will accommodate 2' high clerestory windows and make the below grade living areas much more liveable

   f. When (conventional, clerestory) windows are used, say with 3' high sills, earth can be bermed to the first floor sills

   g. Maximum utilization of passive solar can be obtained with an earth berm that reaches to the roof eave; (light, ventilation) becomes an important concern in this design, and attention to ground water pressures and waterproofing are especially important

6. Complete the following list of statements concerning entry locks and their uses in passive solar design.

   a. Large amounts of heated or cooled air may escape from a home each time a door is opened directly to the outside; entry locks decrease this heat loss and ________ ____________________

   b. An entry lock is designed to provide two doors, only one of which is normally open at any moment, separated by a small unheated or uncooled ____________ ____________________

   c. An entry lock may be designed into the interior of the house

   d. An entry lock may be designed onto the exterior of the house or ____________ ________________________________

7. Select true statements concerning greenhouses and their uses as entry locks in passive solar design by placing an "X" in the appropriate blanks.

   ______a. An entry lock designed as a greenhouse takes advantage of radiation through large glass areas to keep temperatures at higher than average levels, even without supplementary heating, in winter

   ______b. By adding plants and other insulating and shading devices, an entry lock greenhouse can moderate heat gain in summer ______c. An entry lock greenhouse increases the thermal resistance of the inside envelope of a house by

1. Increasing the outside temperature of the main exterior wall in cold weather and decreasing it in warm weather

2. Reducing infiltration losses around doors and windows

______d. When so designed, an entry lock greenhouse can be utilized in the summer for growing vegetables and other plants

8. Solve the following problem concerning window shutters and their use in passive solar design: Window shutters are decorative, but they must have another genuine value; what is that value and what type of shutter would best fulfill that value?

____

____

9. List six passive solar design features that function to complement each other.

a. ____

b. ____

c. ____

d. ____

e. ____

f. ____

10. Match other passive solar concepts on the right with their characteristics.

______a. This can be inclined to the appropriate radiation angle; it retains solar radiation and has operable vents to facilitate heat transfer into the room when the shutter is closed

______b. This collector incorporates collection, storage, and direct venting into the room; would probably have to be used in a southeast room

______c. The berm angle should be the same as the average solar radiation angle for the locale; unit is self-contained and heat is transferred into the home by convection and by manually-operated vents

______d. Usually of concrete or brick, it functions as a natural collector and storage area combined and takes advantage of the convection tendencies of heated air to circulate warmed air through a space

1. Solar window shutter
2. Thrombe wall
3. Solar collectors on earth berms
4. Solar window unit

11. Arrange in order the process for making photovoltaic solar cells by placing the correct sequence number in the appropriate blanks.

______a. The cylindrical ingots are then sliced into wafers

______b. Silicon crystals are grown in cylindrical ingots from purified molten silicon

______c. Silicon crystals obtained from sand go through an extensive purification process

______d. The wafers are then connected and formed into easy to handle modules

12. State how a photovoltaic solar cell works.

a. ____

____

b. ____

____

13. Match the components of a photovoltaic system on the right with their functions.

______a. Supply a fixed current through interconnections between modules or arrays of modules

______b. Act as buffers between the solar cell array and the load, the device using electricity; supplies power to the load during periods of insufficient sunlight and recharged during periods of high sunlight

______c. That part of the power conditioning equipment which prevents battery current from draining back into the array at night when the system is not producing power

______d. That part of the power conditioning equipment which prevents the batteries from overcharging, a condition which shortens battery life

______e. That part of the power conditioning equipment which changes the direct current produced by the photovoltaic array into alternating current

______f. An arrangement in a larger photovoltaic application whereby a local utility purchases excess electricity produced by the system during sunny days, and supplies the user with electricity during cloudy days or at night when the system requires more electricity than it can produce

1. Inverters
2. Blocking diode
3. Solar cells
4. Voltage regulator
5. Storage/backup system
6. Storage batteries

14. Match the terms concerning solar access on the right with their correct definitions.

_____a. That portion of the sky a collector must "see" to perform effectively

_____b. Time expressed in relation to the position of the sun in the sky

_____c. The time at which the sun is at its highest point in the sky

_____d. December 21; the time when the sun is at its lowest altitude in the sky and shadows are the longest

_____e. Usually June 21; the time when the sun is at its highest altitude in the sky and shadows are the shortest

1. Solar noon
2. Summer solstice
3. Solar skyspace
4. Solar time
5. Winter solstice

15. Complete the following list of statements concerning solar azimuth and its use in solar access planning.

a. Solar azimuth is measured ______________________, with a negative value to the east and positive value to the west

b. Since solar access planning involves protecting solar collectors from obstructions lying to the south of the collectors, the concept of a true south solar azimuth makes it easier to ______________________________ and the casting of shadows

16. Select true statements concerning skyspace and its use in solar access planning by placing an "X" in the appropriate blanks.

_____a. The angles of solar altitude and solar azimuth define skyspace, and it is skyspace that must be protected from shading by trees, buildings, or other obstructions

_____b. The altitude of the sun on December 31 and June 31 determines the upper and lower boundaries of needed skyspace

_____c. 45 degree solar skyspace azimuths are suitable for latitudes up to 40 degrees north

_____d. At latitudes under 40 degrees north, solar skyspace azimuths should be 50 degrees for both a.m. and p.m. angles (Transparency 3)

17. Circle the words which best complete statements concerning rules of thumb for planning solar access.

a. In most cases, it is the (lowest, highest) altitude of the sun reached on December 21 that is most important for protecting solar access

b. On December (21, 31) shadows are the longest, and it is usually safe to assume that if longer shadows do not shade a collector, then shorter shadows will not shade it, either

c. It is not necessary that solar collectors be guaranteed access to the sun from sunrise to sunset because solar altitudes below (12, 22) degrees are essentially useless for solar energy collection purposes

d. It is almost impossible to maintain complete open space from horizon to horizon around (a solar collector, solar skyspace)

e. The solar skyspace that must be protected is also dependent on the nature of the solar energy system being used, and the time of day and (month, season) of the year in which it is to be used

18. Match the basic levels of solar access on the right with their correct requirements.

_____a. Protects the sunlight falling on south-facing rooftops of new dwellings and apartments constructed in a community

_____b. Protects south walls of new construction

_____c. Protects part of a lot adjacent to a south-facing wall

_____d. Protects part of a lot for use by detached solar systems

1. South lot protection
2. Detached collector protection
3. Rooftop protection
4. South wall protection

19. Select true statements concerning shadow patterns and their significance by placing an "X" in the appropriate blanks.

_____a. A shadow pattern is the composite shape of a shadow cast by an object over fixed solar azimuths

_____b. A shadow pattern represents every spot shaded by an object during an entire time period, although only a small portion of shadow pattern will be shaded at any given time

_____c. Summer shadow patterns are most valuable because they represent the worst-possible-case, and when solar access is protected in summer, it is usually protected in winter

_____d. Shadow pattern data, whether collected by aerial photographs or taken in a car with a "windshield survey," should be taken at least two times; morning and afternoon on December 21

_____e. Shadow patterns may be calculated only by using shadow length tables

20. List three tree characteristics that must be considered in solar access planning.

a. ____

b. ____

____

c. ____

21. Solve the following problem concerning topography and its relation to solar skyspace: A solar application dictates that the collector will be on a north slope aimed at the crest of a hill; what shading and shadowing problems should be carefully considered?

____

____

22. Complete the following list of statements concerning regulations and codes affecting solar applications.

a. Solar access laws--Laws passed by state or local governments; these laws restrict the building of structures that would block neighboring sites from access to __________________________________

b. Solar easements--State or local laws which set specific space requirements for solar access in much the same manner that easements are set aside for ______________________________

c. State and local building codes--Codes setting up standards for ______________________________ and general structural component quality of structural materials; some codes have been modified to expressly treat solar applications and others have not; it is always best to check local codes, in particular, before starting a solar application

d. Guidelines for solar collector installation on roofs--Since solar systems require maintenance, considerations must be given to the placement of collectors; rooftop ____________________ have to be installed so maintenance personnel can walk around the collectors, collectors must be a safe distance from the edge of the roof, and installation procedures should respect the integrity of the roof

23. Calculate the shadow pattern of a pole.

24. Demonstrate the ability to:

a. Orient a model house and landscape a model lot for maximum solar benefit.

b. Build and operate a solar still.

(NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

PASSIVE SOLAR AND OTHER SOLAR CONCEPTS
UNIT IV

ANSWERS TO TEST

1. a. 2
   b. 5
   c. 7
   d. 1
   e. 4
   f. 6
   g. 3
   h. 8

2. a, d, e, g

3. It is impossible to include more insulation in the roof than in the walls, and window area can be reduced, yet still provide major window exposure to the south

4. a. Central
   b. Windows
   c. Skylight
   d. Insulated shutters
   e. Heat gain

5. a. Humidity
   b. Tree roots
   c. Cold winter winds
   d. 55°F
   e. Below
   f. Conventional
   g. Ventilation

6. a. Heat gain
   b. Air space
   d. Added to an existing house

7. b

8. Window shutters must have a genuine insulating value, and a shutter with a wood face and an insulating core would best fulfill that value

9. Any six of the following:

   a. One-story rectangular configuration
   b. Minimum perimeter distance
   c. Window shutters
   d. Atrium and entry locks
   e. Earth berming
   f. Maximum insulation in roof and walls
   g. Weatherstripping and storm windows

10. a. 1
    b. 4
    c. 3
    d. 2

11. a. 3
    b. 2
    c. 1
    d. 4

12. a. When sunlight strikes the solar cell, internal electrons are energized and electricity is generated
    b. Useful electricity is drawn off through wires attached to the cell

13. a. 3
    b. 6
    c. 2
    d. 4
    e. 1
    f. 5

14. a. 3
    b. 4
    c. 1
    d. 5
    e. 2

15. a. From true south
    b. Determine skyspace and analyze shading

16. a, c

17. a. Lowest
    b. 21
    c. 12
    d. A solar collector
    e. Season

18. a. 3
    b. 4
    c. 1
    d. 2

19. a, b

20. Any three of the following:

    a. Mature height of trees of a species
    b. Mature diameter of the tree crown
    c. Seasonal variations in foliage, taking into account the distinction between deciduous species, most of which shed leaves in autumn, and evergreen or conifers which mostly do not shed leaves
    d. The distance from the ground to the crown

21. Even very short objects may cast shadows on the collector

22. a. The rays of sunlight
    b. Utilities
    c. Plumbing, electrical, mechanical
    d. Traffic pads

23. Evaluated to the satisfaction of the instructor

24. Performance skills evaluated to the satisfaction of the instructor